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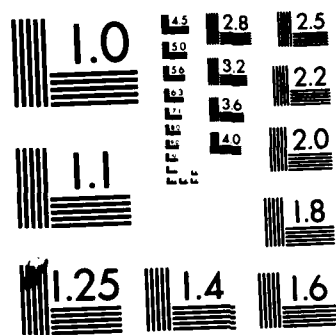
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Military Nutrition Research Annual Report
September 30, 1982—September 29, 1983

Committee on Military Nutrition Research
Food and Nutrition Board
Commission on Life Sciences
National Research Council

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The Committee on Military Nutrition Research was established under the Food and Nutrition Board of the National Research Council's Commission on Life Sciences at the request of the Assistant Surgeon General of the Army. The Committee's task was to advise on the need for and the conduct of nutrition research and related issues for the U.S. Department of Defense. The Committee was asked to identify nutritional factors that may critically influence the physical and mental performance of military personnel under all environmental extremes; to identify deficiencies in the existing data base; to recommend approaches to —

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study the relationship of diet to physical and mental performance; and to rev····
and advise on nutritional standards for military feeding systems.

The Committee identified and provided recommendations on the following four
priority military nutrition issues:

    a. Cognitive testing methods in military nutrition research;

    b. Prediction of the effects of energy and water deficits on military
performance;

    c. Methods for improving hydration under environmental stress, ·····

    d. Surveillance of nutrients in operational rations. ;

The Committee reviewed and provided comments on the Army Regulation 40-25,
"Nutrition Standards and Nutrition Education" and on a proposed plan for test···
the effects of prolonged feeding of the Meal, Ready-to-Eat ration.

The report includes a bibliography with abstracts of over 100 scientific
publications on energy and water requirements under conditions pertinent
to military operations.

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ACKNOWLEDGMENTS

SUMMARY

The Committee on Military Nutrition Research was established under the Food and Nutrition Board of the National Research Council's Commission on Life Sciences at the request of the Assistant Surgeon General of the Army. The committee's task was to advise on the need for and the conduct of nutrition research and related issues for the U.S. Department of Defense. The committee was asked to identify nutritional factors that may critically influence the physical and mental performance of military personnel under all environmental extremes; to identify deficiencies in the existing data base; to recommend approaches to study the relationship of diet to physical and mental performance; and to review and advise on nutritional standards for military feeding systems.

In its first year the committee met four times. The major emphasis of its discussions has been identifying nutritional factors that may influence performance under conditions of demanding military missions. In addition, the committee was requested to review the draft "Nutritional Standards and Nutrition Education" prepared by the Office of the Surgeon General of the Army (AR 40-25, April 9, 1982) and to comment on the proposed plan for prolonged feeding of MRE (meal, ready-to-eat) rations.

The committee identified a number of issues that might be studied. Committee members prepared brief discussion papers on several subjects, papers which the committee then discussed in detail. On the basis of these discussions the committee identified four issues for futher in-depth review and others to be considered at future meetings along with any new topics that may be identified as important. The four issues selected for detailed review were the following:

1. cognitive testing methods in military nutrition research
2. predicting the effects of energy and water deficits on military performance
3. methods for improving hydration under environmental stress
4. surveillance of nutrients in operational rations.

The following are the committee's specific recommendations for review of the four issues:

1. A workshop should be conducted to describe the methods of cognitive testing most likely to be useful in evaluating the effects of nutritional factors on military performance.

2. A workshop should be conducted to identify models that will predict decrements in military performance for various degrees of inadequate energy and water intake. The workshop would foll~' a literature review, which would be used to construct and eva   .t~ various computer models. These models would establish bas(nes to evaluate the effects of caloric and water deficits on perf(.~nce and to help identify topics that may require additional resear

3. Since water is the most essential of all nutrients,   /'~eports have indicated that casualties associated with dehydration ~~ compromised the success of military operations, methods for ~mproving hydration under environmental stress should be evaluated. A specific workshop may be required to do so, but this workshop might be integrated with that discussed under (2) above.

4. Testing systems should be developed to assess changes in the nutrient content and nutrient availability of operational rations over their shelf-lives when subjected to the most extreme storage conditions that may occur. Since combat rations may provide the total food intake for extended periods of time (more than 30 days), changes in nutrient composition that may adversely affect military performance should be assessed.

The committee plans to develop more detailed plans during the next year for ranking and evaluating nutritional issues of interest to the Department of Defense.

CONTENTS

ANNUAL REPORT OF THE
COMMITTEE ON MILITARY NUTRITION RESEARCH

INTRODUCTION

The Committee on Military Nutrition Research was established under the
Food and Nutrition Board of the National Research Council's Commission
on Life Sciences in October 1982 in response to a request from the
Assistant Surgeon General of the Army. The committee's task was to
advise on the need for and the conduct of nutrition research and
related issues for the U.S. Department of Defense. The general
objectives of the committee are to identify nutritional factors that
may critically influence the physical and mental performance of
military personnel under all environmental extremes; to identify
deficiencies in the existing data base; to recommend research that
would remedy these deficiencies; to recommend approaches for studying
the relationship of diet to physical and mental performance; and to
review and advise on nutritional standards for military feeding
systems. The committee members together have expert knowledge of
clinical human nutrition research, including that on mass-feeding; of
human physiology, with emphasis on the environment and exercise; of
performance psychology, encompassing the cognitive, mental, and
psychomotor components of behavior; of food science and technology and
nutrient stability; and of nutrition education, including experience
in human nutrition research (Appendix A).

The nutrient requirements of the armed services and the problems of
satisfying such requirements vary widely with location and the
activity of personnel. Military planners have stated that future
military encounters will be extremely intense and fought with highly
mobile units widely dispersed over the battlefield. Sustained
physical and mental performance under severe physiological and
psychological stress are projected for future battlefield action.
Better information is required about the diet and nutritional factors
needed to sustain performance under these demanding conditions. The
Committee on Military Nutrition Research is pursuing its discussions
on these mission-oriented requirements. (The nutrient requirements of
military personnel under garrison conditions are considered not
substantially different from those of the civilian population.)

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During the last year, tne committee held four meetings (Appendix B). This report summarizes the activities of the committee from September 30, 1982, to September 29, 1983.

As a first task, the committee was asked to comment on the draft "Nutritional Standards and Nutrition Education," prepared by the Office of the Surgeon General of the Army (AR 40-25, April 9, 1982). The draft regulation defines responsibilities of the Surgeons General of the U.S. Army, Navy, and Air Force; establishes nutritional standards for daily food allowances and operational rations; and provides basic guidelines for nutrition education. The regulation applies to all active and reserve components of the military. A letter report conveying comments and recommendations on this regulation was transmitted to the sponsor on December 17, 1982 (Appendix C).

During its second meeting the committee conducted a miniworkshop on prolonged feeding of MRE (meal, ready-to-eat) rations. A summary of the comments of the committee is given in Appendix D.

During its deliberations on specific mission-related issues of significance to the military, the committee identified the following subjects as those important to study:

1. cognitive testing methods in military nutrition research
2. predicting the effects of energy and water deficits on military performance
3. methods for improving hydration under environmental stress
4. surveillance of nutrients in operational rations
5. the effects of stress on nutrient requirements
6. nutrient solutions for troops wearing protective clothing
7. the effects of foods and nutrients in overcoming jet lag
8. nutrition as a countermeasure to NBC (nuclear, biologic, and chemical) warfare
9. the effects of severe stress on intake of food and water
10. epidemiological data derived from information on career personnel
11. computer-assisted monitoring of the nutritional contents of garrison rations.

Of these, the committee decided to review in greater depth the first four topics. They appear to be most important to the military, and meaningful progress in studying them is possible within reasonable time.

The following sections summarize committee discussions on these subjects and recommend the following steps to take.

COGNITIVE TESTING METHODS IN MILITARY NUTRITION RESEARCH

At this time investigators do not agree about developing sensitive methods to assess the effects of dietary or other environmental

variables on the performance of military personnel. This lack of
agreement results largely from the fact that no methods for testing
cognitive performance are generally accepted as valid predictors of
effective performance in combat or other military situations. Over
the last several decades, researchers in psychology, biology, and the
neurosciences have made substantial progress in understanding the
cognitive processes and neural mechanisms involved in human
performance in fairly restricted but well-defined domains, such as
verbal learning (Bower, 1977), signal detection (Egan, 1975; Posner,
1982), tracking (Wickens and Gopher, 1977), and analogical reasoning
(Sternberg, 1977). Nevertheless, such understanding does not allow
performance to be predicted with any certainty in situations as
complex as those encountered by military personnel. Considerable
progress has also been made in developing testing methods that
simulate aspects of performances in operational environments,
performances like driving a car (Moskowitz et al., 1976), flying a
plane (Gopher, 1982) and monitoring a radar screen (Colquhoun, 1975).
Still, it is not yet possible to simulate all the situations that
military personnel are likely to encounter nor to predict performance
from one situation to another with certainty.

The problem in studying the effects of nutrients or environmental
manipulations on military performance is how to select assessment
procedures that are practical, that are likely to be sensitive to the
variables of interest, and that are valid predictors of military
performance. Because current knowledge does not suggest that any
particular testing methods will be best in all cases, the problem is
then how to choose from among available methods those most appropriate
for a given study.

Several actions thus seem advisable. Information should be
assembled on available methods of cognitive testing that will likely
be useful in assessing nutritional effects on military performance.
Also, an attempt should be made to formulate guidelines for
researchers in this field to use in selecting appropriate performance
measures and in identifying specific research projects that could
substantially improve our ability to assess the effects of nutrition
on military performance.

As a result of recent developments in military technology,
effective military performance is increasingly a function of soldiers'
ability to perform complex cognitive and psychomotor tasks. To
determine the effects of nutritional and other environmental
manipulations on military performance, reliable and valid predictors
of performance in complex cognitive and psychomotor tasks will have to
be developed. A review of current work in this field could greatly
increase the ability of military planners to predict the effect of
dietary restrictions, schedule changes, nutritional improvements, and
related factors on the performance of military personnel.

One first step toward a coherent approach to cognitive testing
methods would be a workshop bringing together scientists performing
research on cognitive testing and researchers from Department of

Defense laboratories. Before the workshop, a review of previous work
on the effects of nutrient deficiencies on cognitive performance
should be prepared and distributed to participants, and participants
should be asked to prepare papers for presentation on topics like the
following:

o   methods for studying the reliability and validity of tests of
military performance
o   the use of batteries of cognitive tests to evaluate deficits in
cognitive performance
o   the use of simulators (e.g., of flight, radar monitoring, and
driving) to assess deficits in cognitive performance
o   measures of motivation and morale as indicators of potential
deficits in performance
o   simulated work environments for measuring military performance
o   tests of the efficiency of man-machine interactions to measure
military performance
o   the validity and sensitivity of methods to measure behavior of
individuals in small groups.

Representatives of various Department of Defense laboratories engaged
in testing cognitive performance should be asked to attend. They
should be requested to present summaries of their current research
programs, conclusions, and plans. The committee recommends that a
workshop be conducted to describe the available methods of cognitive
testing that will be most useful in evaluating the effects of
nutritional factors on military performance and to identify subjects
in which research could improve these methods. Both should contribute
toward better understanding of how nutritional variables affect
military performance.

PREDICTING THE EFFECTS OF ENERGY AND WATER
DEFICITS ON MILITARY PERFORMANCE

Toward determining human nutrient requirements in future military
operations, the committee reviewed the literature on food and water
use. These data are to be used to develop tables, computer models,
and other summaries for prediction. Review of the literature
indicates that many factors influence caloric and water requirements.
Major ones include body size, clothing, climate, physical activity,
work-rest cycles, and terrain. These variables and others will be
considered in developing tables and prediction equations. The
literature reviewed is presented here as a bibliography along with the
authors' original abstracts (Appendix E). This review produced much
useful information about specific aspects of energy and water supply
to support troops in the field.
The computer models of energy and water requirements derived from
the data supplied by this review not only will provide a useful

summary and predictive equations, but should also reveal deficiencies in our knowledge in order to guide essential research. Development of the models will more generally reveal the strengths and weaknesses of the data base. Given additional data, the summaries, equations, and models can be refined to be more accurate and practical. Factor analysis or other statistical approaches, which can identify variables most likely to influence requirements in some systematic way, will also be used to improve the summary information. If important gaps in our knowledge are revealed, a workshop could explore experimental approaches that might fill them. Even now, for example, one unknown factor is how troops will be moved, deployed, and used in future field exercises and combat.

Developing such summaries will help establish the baselines necessary for evaluating the effects of caloric and water deficits on performance. Military personnel in stressful environments and conditions of limited logistical support may be forced to sustain their activities given limited rations or water or both for days or even weeks. Possible resulting deficits in performance, including cognitive and psychomotor performance, need to be predicted. Such predictions are likely to be highly variable, or at least uncertain initially. In this regard, a workshop dedicated to considering the prediction of deficits could be most useful (see the following section). On the basis of an initial and cursory review of the literature on the effects of energy and water deficits on various types of performance, the data base appears indeed sparse. Extension of the prediction equations should include consideration of small, moderate, and large deficits that persist over different periods of time. Further extension could attempt to predict casualties in addition to performance decrements.

The committee recommends a workshop to identify models that will predict decrements in military performance for various degrees of inadequate energy and water intake. Part of the workshop should be devoted to evaluating the strengths and weaknesses of the data from the literature with regard to constructing computer models. Another part should identify gaps in our knowledge and suggest experimental approaches to fill them.

METHODS FOR IMPROVING HYDRATION UNDER ENVIRONMENTAL STRESS

Water is the most essential of all nutrients. Casualties associated with dehydration have compromised the success of many military operations. Many factors influence water balance during military operations in specific environments. The following are among the more critical:

o   the amount of physical activity required
o   the environmental conditions, e.g., extreme heat or cold or exposure to solar radiation at high altitude

o   the physical conditioning and acclimatization of personnel
o   proper training in use of survival equipment and techniques
o   hydration status before the exercise
o   access to an appropriately designed hydration solution to
increase fluid intake and to maximize water and electrolyte balance.

Research has drawn attention to the importance of basing guidelines
on conditioning, hydration, and wet-bulb globe temperature in
preventing heat casualties. Research to develop an appropriate
hydration regimen for various operational requirements and
environments could further improve the performance of troops and
ultimately provide a tactical advantage to military units operating in
environmental extremes (Bijlani, 1980; Gisolfi; 1974; Knochel, 1974;
Torranin, 1979).

Human performance is severely affected by dehydration. Once a
soldier loses more than 5 percent of body weight as water, his or her
vital systems will begin to fail. The issue then becomes survival,
not how to perform a task. Little is known about the physical and
cognitive deficits that result from less severe dehydration.

The committee deliberated at length on current knowledge, and lack
of knowledge, about the maintenance of hydration and about its
importance in sustaining optimal performance. Principal observations
and conclusions were as follows:

o   The scientific literature contains modest amounts of relevant
data, but much more is probably presented in the unpublished reports
of military laboratories (including those of allied nations, such as
Canada and the United Kingdom) that have not been readily available to
the greater scientific community. Such laboratory reports would
include those of the U.S. Army Medical Research and Nutrition
Laboratory and the Letterman Army Institute of Research.

o   The greatest part of readily available work has focused on
preventing heat-induced dehydration at various humidities. Much less
is known about the importance of maintaining hydration in other
environmental extremes, particularly under operational conditions in
extreme cold and at terrain altitudes greater than 10,000 ft (3,000 m).

o   Although generalities about performance decrements given
various degrees of dehydration are known (Bijlani, 1980; Gisolfi;
1974; Knochel, 1974; Torranin, 1979), the variability among individual
soldiers' performances has not been adequately explored under the many
operational and dietary conditions that may occur (see the previous
section).

o   The issue of whether to provide water alone or along with
electrolytes or readily available calories remains unresolved. The
committee feels that solutions containing moderate amounts of
electrolytes and small amounts of readily available carbohydrate are
probably useful in maintaining hydration and in minimizing the adverse
effects of dehydration. This conclusion is based on research showing

accelerated water uptake from such solutions (Hecker, 1983). The optimal composition of such solutions, however, is not known.

o The thirst mechanism can fail in extreme environments, with dehydration resulting unless fluid intake is virtually forced. The mechanism of thirst failure is not known, nor have possible dietary or chemopreventive approaches to this problem been well explored.

o If tactical or survival situations are likely to involve small numbers of soldiers in isolation for considerable periods--e.g., several days to a week--with subsistence consisting of nutrient-dense "survival" rations, the importance of a soldier being able to provide himself with potable water becomes obvious. The technology of water purification for such circumstances appears to have lagged.

The committee recommends that a workshop be held, using a literature review as the starting point, to identify the research needed to improve hydration under environmental stress. It should consider the specific topics outlined above and any other important related issues that may emerge. This workshop might be integrated with that on computer models described above.

SURVEILLANCE OF NUTRIENTS IN OPERATIONAL RATIONS

Military rations differ from civilian feeding systems in three ways: first, in combat situations, the soldier may have to depend completely on combat rations for energy and nutrients; second, rations are expected to have longer shelf-lives than commercial foods (4 to 6 years, rather than 1 to 2 years); and third, in hostile environments, military rations are likely to be exposed to more adverse temperatures and humidities than foods in domestic warehouses. Because rations could be used for periods longer than 30 days, changes in their nutrient composition during such storage, which may adversely affect military performance, need to be assessed.

During the development of the MRE (meal-ready-to-eat) ration, selected nutrients were assayed in menu composites held at controlled temperatures for specified periods of time. Prototype and current studies of the MRE are not designed to assess the rate of nutrient destruction that would occur if rations were inadvertently stored at 120 to 145°F, which could occur during transport or storage under wartime conditions.

Data available in the scientific literature imply dramatic losses of vitamins A, E, and C in MRE rations stored for extended periods above 85°F (Goldblith, 1971). Substantial losses of thiamin, riboflavin, and vitamin B_6 would also be expected in rations that were subjected to storage temperatures of 120 to 150°F.

The bioavailability of macronutrients, including proteins and lipids, may also be affected by storing military rations at high temperatures. These losses could occur because of browning reactions and lipid oxidation, which can result in the cross-linking of lipids

and proteins. The chemical reactions would result in important losses in the nutritional values of the rations because they would decrease absorption in the gut (Gardner, 1979).

The committee encourages the development of testing systems to assess changes in nutrient contents and availability over the shelf-lives of all operational rations subjected to realistic, but adverse, storage conditions. Annual peacetime procurement of military rations ranges from $100 to $200 million. Such an investment deserves periodic assessment to ensure that the nutritional standards for combat rations are met not only at the time of procurement, but, more importantly, at the time of consumption.

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APPENDIX A

BIOGRAPHIC SKETCHES
COMMITTEE ON MILITARY NUTRITION RESEARCH

Elsworth R. Buskirk received a B.A. in biology and physical education from St. Olaf College in 1950. The University of Minnesota awarded him an M.A. in physiological hygiene and physical education in 1951 and a Ph.D. in physiological hygiene in 1953. From 1954 to 1963 he was with the U.S. Army Quartermaster Research and Development Command and the National Institutes of Health. He then joined the faculty of the Pennsylvania State University and initiated the Laboratory for Human Performance Research, which emphasizes applied human physiology. His current appointments are director of the laboratory and chairman of the physiology program. He holds professorships in applied physiology, human nutrition, and bioengineering. He has served on a variety of study groups for the National Institutes of Health and committees of the National Research Council. Dr. Buskirk's major research interests include physiology of exercise; environmental physiology; and calorimetry, metabolism, and nutrition.

Allan L. Forbes received his B.Sc. from McGill University, Montreal, in 1949, and his M.S. in biochemistry and M.D. from the Medical College of Virginia in 1953. Dr. Forbes has had a career in serving the governments of the United States and Canada. After his medical training, which included several years with the U.S. Army Medical Research and Nutrition Laboratory, he served with the U.S. Veterans Administration, the U.S. Department of the Army, and the interdepartmental Committee on Nutrition for National Defense. In 1970 Dr. Forbes joined the U.S. Food and Drug Administration's Division of Nutrition. He was director of the Nutrition Bureau of the Canadian Department of National Health and Welfare from 1973 to 1974. In 1979 he became associate director for Nutrition and Food Sciences, Bureau of Foods, U.S. Food and Drug Administration. He is the author of numerous papers and reports in clinical nutrition. He received the Conrad A. Elvehjem Award for Public Service in Nutrition from the American Institute of Nutrition in 1982, and the Public Health Service Superior Service Award in 1983. He is president-elect of the American Society for Clinical Nutrition.

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Arthur L. Hecker received his B.S. and M.S. from Montana State
University in nutrition and biochemistry. His Ph.D. in nutrition was
awarded by Colorado State University in 1972. He was on the faculty
of Colorado State University and served with the U.S. Army Medical
Research and Development Command as chief of the Protein-Carbohydrate
Group of the Letterman Army Institute of Research. Dr. Hecker is
currently the director of medical nutritional research at Ross
Laboratories, Columbus, Ohio. He is a member of the American
Institute of Nutrition and a fellow in the American College of Sports
Medicine. Dr. Hecker has published over 30 papers in the area of
nutrition, which focus on metabolic adaptation to stress. Twenty of
these publications address the nutritional aspects of physical
performance.

D. Mark Hegsted received his B.S. in nutrition from the University of
Idaho in 1936 and his M.S. and Ph.D. in biochemistry, in 1938 and
1940, from the University of Wisconsin. He is now professor of
nutrition emeritus at Harvard University and associate director for
research, New England Regional Primate Research Center, Harvard
Medical School. He was administrator of the Human Nutrition Research
Center, U.S. Department of Agriculture, from 1978 to 1982. Dr.
Hegsted is a member of the National Academy of Sciences and former
chairman of the Food and Nutrition Board. His research interests
include comparative nutrition, protein requirements, and the
relationship between diet and coronary heart disease.

James R. Kirk received his B.S. in biology from the College of the
Holy Cross in 1964. He obtained an M.S. in food science in 1966 and a
Ph.D. in food science and human nutrition in 1971 from Michigan State
University. From 1971 to 1978 he was professor of food chemistry in
the Food Science and Human Nutrition Department of Michigan State
University. From 1978 to the present he has been professor and
chairman of the Department of Food Science and Human Nutrition at the
University of Florida, Gainesville, Florida. Dr. Kirk has received
many citations and awards during his career, including the Institute
of Food Technologists' Babcock-Hart award in 1983. His main research
interests are the influence of processing and storage on nutrient
stability and bioavailability in foods and new analytical methods for
the chemical determination of vitamins in biological materials.

David A. Levitsky received his B.S., M.S., and Ph.D. from Rutgers
University in the years 1964, 1966, and 1968. He was a postdoctoral
fellow at the National Institutes of Mental Health for two years
before joining the Department of Pathology and the Division of
Nutritional Sciences at Cornell University. His research interests
include the effect of nutrition on brain and behavior, the control of
food intake, and the regulation of body weight. He is a member of the
American Institute of Nutrition and the American Psychological
Association.

Richard C. Mohs received his B.S. in psychology from the College of William and Mary and his Ph.D. in psychology from Stanford University. He had a postdoctoral fellowship in psychopharmacology at the Stanford University School of Medicine. Dr. Mohs is currently an assistant professor in the Department of Psychiatry of the Mount Sinai School of Medicine and a psychologist for the Psychiatry Service of the Bronx Veterans Administration Medical Center, Bronx, New York. Dr. Mohs' research interests include psychopharmacology, aging, and the cognitive effects of drugs and diet.

Robert O. Nesheim received his B.S., M.S., and Ph.D. in nutrition from the University of Illinois in 1943, 1950, and 1951. Prior to his retirement from the Quaker Oats Company in March 1983, he held a number of positions in research and management there, including vice-president of research and development and vice-president of science and technology. He was professor and head of the Department of Animal Science at the University of Illinois from 1964 to 1967. He had numerous committee assignments with the National Research Council, including one for six years as member of the Food and Nutrition Board. He is currently vice-president of science and technology in research and quality assurance for Cambridge Plan International, Monterey, California.

Paul C. Rambaut is employed by the National Aeronautics and Space Administration, where he manages a nationwide research program aimed at understanding and preventing the harmful effects of space environments on astronauts. He assumed his present position, manager of the Biomedical Research Program, in 1979, after 10 years in research at the National Aeronautics and Space Administration's Johnson Space Center in Houston. Dr. Rambaut earned his B.S. and M.S. degrees in biochemistry at McGill University, Montreal, his Sc.D. in nutritional biochemistry at the Massachusetts Institute of Technology, and his MPH at Harvard University. His research interests are characterization of neurotransmitter substances; sulfur amino acid metabolism; dietary control of cholesterol metabolism; and energy and calcium metabolism.

Catherine E. O'Connor Woteki received her B.S. in biology from Mary Washington College and her M.S. and Ph.D. in human nutrition from Virginia Polytechnic Institute. Dr. Woteki was a clinical researcher at the University of Texas Medical School at San Antonio, an assistant professor in the Department of Nutrition and Food Science at Drexel University, and the Nutrition Project director in the Congressional Office of Technology Assessment. She also held positions of leadership in the Consumer Nutrition Center and the Human Nutrition Information Service of the U.S. Department of Agriculture. She is currently Deputy Director, Division of Health Examination Statistics, National Center for Health Statistics, U.S. Department of Health and Human Services.

Allison A. Yates received a B.S. in dietetics and an M.S. in public
health nutrition from the University of California at Los Angeles.
She received a Ph.D. in nutrition from the University of California at
Berkeley. She is currently assistant professor of community health in
the Division of Nutrition at Emory University School of Medicine in
Atlanta. Her professional interests include research on human protein
and energy requirements and utilization of vegetable proteins.

APPENDIX B

MEETINGS OF THE COMMITTEE ON MILITARY NUTRITION RESEARCH
SEPTEMBER 30, 1982 - SEPTEMBER 29, 1983

November 17-18, 1982	Washington, D.C.
March 16-18, 1983	Natick, Massachusetts
June 27-28, 1983	Washington, D.C.
September 15-16, 1983	Seattle, Washington

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NATIONAL RESEARCH COUNCIL

COMMISSION ON LIFE SCIENCES

FOOD AND NUTRITION BOARD

APPENDIX C

COMMITTEE LETTER REPORT

12/17/82

Major General Garrison Rapmund
Assistant Surgeon General Commander
U.S. Army Medical Research and Development
  Command
Attention: SGRD-PLC
Fort Detrick
Frederick, Maryland   21701

Dear General Rapmund:

   In response to your request, the Committee on Military Nutrition
Research of the Food and Nutrition Board has evaluated the draft
"Nutritional Standards and Nutrition Education" (AR 40-25, 9 April
1982) prepared by the Office of the Surgeon General of the Army.
   The draft AR 40-25, 9 April 1982, represents significant
improvements over the current AR 40-25, 30 August 1976, now used in
military dietary planning. The following comments for your
consideration are based on an analysis of the draft and discussions
with members of your staff and other military personnel at the
November 17-18, 1982 meeting of the committee in Washington, D.C.

   1. The available food composition data bases do not have adequate
information on copper, manganese, and chromium for calculating
nutrient composition of rations for these nutrients. Therefore, it is
suggested that these elements be transferred from Table 1, Military
Recommended Dietary Allowances (MRDA) of Selected Nutrients, on page 5
and 6, to Table 2, Estimated Safe and Adequate Daily Dietary Intake
Ranges of Selected Vitamins and Minerals, on page 8. No biomedical
evidence is available to justify including these nutrients in Table
1. Also, this new placement will be consistent with the listing of
these nutrients in the Recommended Dietary Allowances (Food and

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Nutrition Board, 9th Revised Edition, 1980, National Academy of Sciences-National Research Council).

2. The committee urges that the data in the USDA Food Composition Handbook 8 Series or the most recently available food composition data be used for calculating the nutrient composition of the daily food allowances. However, these data are not adequate for calculations with the nutrients listed in Table 2 on page 8. Thus, the committee recommends the analysis and monitoring of Table 2 nutrients in the daily food allowance over sufficient time to permit a determination of levels of these nutrients in menus.

3. Sodium requirements need special consideration. The committee suggests that this nutrient be listed in Table 1 without specified levels; however, a note should discuss the appropriate levels of sodium in the daily food allowance.

Table 2 lists a range for safe and adequate levels of sodium based on the 1980 RDAs. Although this range will provide nutritionally adequate levels of sodium, other factors must be considered. Under certain work or environmental conditions higher sodium intakes may be required. A recent FDA total diet study has shown that the average sodium intake for a young adult male on a 3200 calorie diet approximates 5500 mg. However, the committee recommends that an effort be made to reduce this intake level in the military feeding system. In achieving lower levels, consideration must be given to the following areas: a) Since actual total daily sodium intake levels are not known, they must be determined; b) Current recipes will have to be revised adjusting sodium content downward to the minimum levels at which food is palatable and acceptable; c) Nutrition education programs alerting military food-preparation personnel as well as military personnel and their families to the importance of reducing sodium intake both in the preparation of foods and at the table will be required; d) As commercial food products used in military menus are reduced in sodium content, the total sodium contribution in the daily food allowance can be brought to more moderate levels; however, careful monitoring of both sodium levels and food acceptance by military personnel will be required.

4. The draft AR 40-25 does not contain any recommendations on the cholesterol content of the daily food allowance. The committee urges the monitoring of the cholesterol content of diets for the purpose of achieving baseline data on current levels. As the data base on cholesterol content of foods is improved and its effects on health are better understood, it may be possible to provide military menu planners with desirable daily intake levels of cholesterol.

5. The committee suggests the following changes for Table 3, Nutritional Standards for Operational Rations (page 13):

a. Since iodine is found in many products, iodine requirements can be adequately met by the amount provided by iodized salt. Additional supplementation is unnecessary.

b. Delete copper, manganese, and chromium. Food composition information on these nutrients is very limited. Also, these nutrients are normally supplied in sufficient amounts in ingredients used in diets, particularly for the short time of subsisting on operational rations. The committee encourages the collection of data on these nutrients.

c. Have the specification for salt and, in particular, the inclusion of salt packets (Note c. on page 14) reviewed by competent authorities to determine the desirability of this requirement under military operational conditions in light of current knowledge.

6. The committee suggests that the last sentence under 6.a. on page 17, "Personnel of larger body size...heavy physical performance," be deleted because current evidence does not appear to support it.

7. The committee suggests that the last sentence under 6.i. on page 21, "In fact, the glucose...the gastrointestinal lumen," be deleted. The committee believes that this comment is irrelevant.

8. The committee recommends that the military explore the use of the Nutrient Density Index (NDI) in diet planning. The numbers in Table 4 on page 23 should be carefully reviewed to be certain that they are consistent with the MRDAs in Table 1 and appropriate for those nutrients not utilized in proportion to calories. In addition, an evaluation should be made to determine whether the NDI levels under the weight reduction diet (1500 calories) in Table 4 can be achieved without supplementation.

9. Under 4. Nutrient Standards for Operational Rations (page 11) the next to last sentence reads: To minimize performance degradation, the restricted ration should provide 1200-1500 kcal/day, 50-75 gm protein, and a minimum of 100 gm carbohydrates. The committee recommends that this provision be reviewed and modified to prevent excessive (over 50 percent) amounts of calories coming from fat, and that the words "at least" be inserted in the sentence before "1200-1500 kcal/day."

The last sentence reads: Vitamins and minerals should be provided at the levels prescribed in Table 3. The committee believes these levels are not necessary. For this short term use of the ration, levels of vitamins and minerals could be provided at no more than 1/2 that specified in Table 3.

10. The committee agrees with the recommendations in AR 40-25, 9 April 1982 (item 6.b., page 17), that calories derived from total dietary fat should not exceed 35 percent under garrison feeding conditions. This percentage is reasonable, achievable, in line with current dietary guidelines, but will require careful menu planning to assure acceptance of meals.

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

Please call me if you have any questions.

Very truly yours,

Robert O. Nesheim
Chairman, Committee on Military
  Nutrition Research

Attachment

cc: Irwin H. Rosenberg
     Myrtle L. Brown
     Frank R. Fisher
     LTC David D. Schankenberg
     Committee Members

APPENDIX D

SUMMARY OF A MINIWORKSHOP ON PROLONGED FEEDING OF
MRE (MEAL, READY-TO-EAT) RATIONS,
MARCH 17, 1983

An MRE feeding study is planned for the 25th Division in Hawaii. The committee's discussion of this plan centered primarily on the material provided by Lt. Col. David Schnakenberg in the paper "Scenario for Test of Effects of Prolonged Feeding of MRE Rations" (attached) and the presentation by Dr. Edward Hirsch of the U.S. Army Natick Research and Development Laboratories. The following is a summary of the committee's comments.

The committee expressed considerable concern over plans to evaluate the MRE ration over a 45-day period using one company of troops in field training. The major concern is that the study will likely yield an overcritical and biased assessment of the MRE ration. It is well known that food is important in maintaining morale in any population, and troops are likely to be critical of their food supply. It is also very likely that in any prolonged test the MRE ration will be more monotonous and less acceptable than the traditional "A" ration, regardless of nutritional quality. Those in the company receiving the MRE ration might be perceived by themselves and others as being at some disadvantage, and the MRE ration could even be used as an excuse for poor performance.

The acceptability of a ration and the performance of a company of troops obviously depend in large part on leadership. In a one-company test, there is no way to take this effect into account.

The MRE ration has been developed over a considerable period with large expenditures of effort and money. The ration has been formulated to provide recommended amounts of nutrients as specified in the RDA of the National Research Council.

Because the primary concern is acceptability over a long period, the MRE ration should be tested under conditions that give reason for believing that a favorable outcome is likely. Frequent questioning about the acceptability of the ration and its individual items would almost guarantee a more critical evaluation than would occur in an actual field situations where there are no known alternatives (such as "A" rations). It might be possible to avoid this difficulty by placing all the troops in the field at one time on the MRE ration for a shorter period, to obtain acceptability information based on a large number of troops and to keep the views of one small group from being singled out.

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A long-term evaluation of the MRE ration could eventually be carried out. This might be done when some of the chief complaints are known, and if necessary corrected, and when troops are more familiar with and therefore less suspicious of the food and the feeding system.

The committee concluded that food consumption and hydration status of the users of the MRE ration were the most important aspects of the proposed 45-day feeding of the ration. There is no reason to believe that it is nutritionally unsatisfactory over the period that it will be used. It is the acceptability of the ration that is the primary concern. If the troops eat the ration in satisfactory amounts, they will receive appropriate nutrient intakes. Because military populations are expected to be healthy and in relatively good nutritional status when they enter the study, no significant measurable changes in nutritional status would be anticipated during the 45-day period if the MRE ration is consumed in adequate amounts. However, if acceptability is low, evaluation of the MRE ration should focus on the measurement of food consumption. Some components of the MRE ration are dehydrated and may be consumed without rehydration so water consumption can be important. Also, troops may be more dispersed when using the MRE ration than when using the "A" ration, and provision of water or encouragement of consumption of water may not be comparable for the two rations. Therefore, the hydration status of troops consuming MRE rations must be carefully evaluated.

Responding to field questionnaires could probably be an integral part of each day's activities, with individual soldiers completing them immediately after eating. This would call attention to the ration and risk a more critical evaluation than might occur if less obstrusive measures of acceptance were used. Collecting refuse or discarded pouches and other means might provide information concerning the more acceptable items and could certainly have value in validating food-consumption questionnaires. In the study of food consumption, it would be useful to obtain information on food preferences at the beginning and during the course of the study to assess changes in them. This information could lead to evaluating the variety of the MRE ration and suggesting acceptable alternatives for the menu.

With regard to physiological, biochemical, and physical measures that might be used in the MRE field study, the committee judged it unrealistic to attempt such measures in detail. As indicated before, data on food preference and consumption and on hydration status are of fundamental interest. Measuring weight change, for example, every two weeks, could give some indication of food intake over the course of the study. Any such change of course, could be influenced by water status and physical activity during various test periods. Comments were made that little could be gained from biochemical measurements and from anthropometric measures other than body weight. However, if blood samples are taken, priority should be given to assaying red-cell aminotransferase activity, serum osmolality, and hemoglobin hematocrit.

Clinical information that might be relevant would be the number of personnel reporting on sick call and the nature of their complaints, such as constipation, diarrhea, and other gastrointestinal disorders.

With respect to behavioral measures, the committee thought that the primary behavioral response to the MRE ration might be a change in morale. Many factors can affect morale among troops so it would be difficult to draw conclusions by comparing the morale of two companies. The experimental design outlined does not allow a valid conclusion about the effect of the ration on performance as measured by cognitive and physical tests. Probably all that could be expected would be field observations of the behavior and performance of the subjects, rather than data from laboratory tests of cognition and behavior. Observation of group morale by trained observers would be less intrusive and would be consistent with other aspects of field operations.

The Committee discussed the potential for a continuing evaluation of MRE rations that would start with a short-term feeding (7-10 days) to a large body of troops; all troops in the field would get the same ration and be carefully observed with regard to food acceptance and attitude. Additional studies could be conducted in which troops were fed rations for longer periods; troops and commanders would be more familiar with the ration, and potential problems of ration acceptance and gastrointestinal disorders might be better understood. A study that will satisfactorily evaluate the nutritional adequacy of the MRE ration would require feeding it for a period much longer than 45 days and with more carefully controlled conditions than are likely to be available when the ration is fed as a part of a field exercise.

ATTACHMENT TO APPENDIX D: SCENARIO FOR TEST
OF EFFECTS OF PROLONGED FEEDING OF MRE RATIONS

Lt. Col. David Schnakenberg

A. Background

The Department of the Army's (DA) policy on duration of use of combat rations is loosely stated in TB MED 141 (1071), IB 8-250 (1974), and TM 8-501 (1961) which collectively advise that the Meal Combat Individual (MCI) ration (the familar "C" ration), although formulated to be nutritionally adequate, should not be used as the sole source of food for periods in excess of ten consecutive days. The rationale given is that the ration will become monotonous, troop acceptance and nutrient intakes will decrease, morale will deteriorate and as a consequence, troop performance and health may be adversely affected. The Army has not established a specific policy regarding use of the Meal-Ready-to-Eat (MRE) Ration which we began procuring in 1980, and troops will begin eating within the next year when the existing MCI

stocks are depleted. Furthermore, no systematic studies have been conducted with the MRE to either confirm or refute the earlier policy for MCI rations.

In 1976, the Army submitted a requirement to the DOD Food RDT&Eng Program to evaluate the effects on troops' morale, performance, nutrition and general well-being when troops are fed combat rations (MCI and MRE) as the sole food source for extended (30-60 days) periods of time. For a variety of reasons, including delays in the MRE procurement program, and most importantly, a lack of a realistic test scenario and available test population, this study has yet to be done. However, during the past year, Natick Laboratories have identified a test scenario that provides the best opportunity to date for conducting a field test in conjunction with regularly scheduled training exercise.

B. Site

Pohakula test site on the Island of Hawaii--warm, arid, remote, evaluation of 5,000 ft and higher.

1. Test Population Two companies (130 troops each) of aggressor forces from 25th Infantry Division, supporting scheduled field training. Troops will be light infantry foot soldiers, moderately to highly active.

2. Dates August-September 1973.

3. Duration of Test Six weeks. We are advised that the test population is scheduled to be deployed for 45 consecutive days without passes on weekends.

4. Food Service Troops are normally fed two "A" rations and one MCI meal per day. The "A" ration is prepared in field kitchens and includes fresh fruits, refrigerated and frozen food items, and fresh bread. Snack items are not readily available, the nearest facility being a small PX in the base camp which is 20 miles from the large training area. No commercial food outlets are nearby.

C. Draft Test Plan

Natick laboratories have proposed a test plan to evaluate the effects of feeding the MRE ration as the sole source of food for 45 days on troop performance, morale and general well-being. The primary investigator for the study, Dr. Ed. Hirsch, research psychologist from Natick Labs, will provide an overview of the proposed study methodologies on 16 Mar 1983.

Very briefly, the study design is that one company of 130 troops will be fed the MRE as their sole source of food for 45 days (experimental group = E) and another company (control group = C) will be fed two "A" ration meals and one MCI meal. The two groups will be

kept geographically separated as much as possible. A subsample of 30
volunteers from each study will be selected for more extensive study.
A brief outline of the proposed test procedures and schedules is
attached. Dr. Hirsch will provide additional details at the meeting.

D. Implications of the Test

The Army will look to the Surgeon General to review and utilize the
data from the test to establish policy regarding the length of time
the MRE ration can be used as the sole source of subsistence without
degrading troop performance, morale or health. That policy will guide
operational and logistical planning on when field kitchens and cook
personnel must be deployed. The data may also be used to propose any
necessary changes to the current MRE menu, nutritional standards or
nutrient fortification procedures.

APPENDIX E

ENERGY AND WATER REQUIREMENTS
UNDER CONDITIONS PERTINENT TO MILITARY OPERATIONS:
A BIBLIOGRAPHY WITH ABSTRACTS

Prepared for the Committee on Military Nutrition Research by committee
member E. R. Buskirk, with the assistance of W. L. Kenney, S. Puhl, C.
Sherarburn, V. Rabatin, and B. Nilson of the Laboratory for Human
Performance Research, Pennsylvania State University

CONTENTS

INTRODUCTION

The purpose of this bibliography is to provide information for
predicting food and water needs for military personnel. Aut ors'
original abstracts accompany each entry in the bibliography.

Predicting food and water needs depends on determining the value of
several variables, including physical activity and environmental
conditions. Summary tables and prediction equations are not included
as part of this presentation, but will be compiled in a later report
if such an effort is supported by the activities of the Committee on
Military Nutrition. The available literature is too voluminous to
cover completely, so representative studies were selected from those
available to us. Unfortunately, current studies of the operational
needs of mobile task forces are not available, although such
information is urgently needed. To our knowledge, this annotated

bibliography represents one of the few attempts to bring together pertinent data on food and water requirements for military operations. Time constraints necessitated compromise in searching the literature; provision of additional resources would make expansion of the present report relatively easy.

Food and water needs are difficult to estimate unless substantial information is available regarding the specific military operation in question. When airborne and mobile task forces depend to only a minor extent on human mobility and load transport their energy needs will be relatively small, but when transport vehicles cannot be used, troops will be forced to move on foot, and that increase in physical activity will increase their food and water needs.

When possible, energy input, turnover, and utilization are expressed in kilocalories. Water allowances are reported in liters. A list of units of measurements and abbreviations is provided.

BIBLIOGRAPHY ON
FOOD UTILIZATION AND ENERGY TURNOVER

Allen, C. L., and W. J. O'Hara. 1973. Energy Expenditure of Infantry Patrols during an Arctic Winter Exercise. Downsview, Ontario: Defence and Civil Institute of Environmental Medicine. DCIEM Report 73-R-985, Dec., 10 pp.

The energy expenditure of infantry troops participating in winter training exercises at Churchill and Frobisher Bay was monitored. Twenty seven personnel comprising three tent groups were studied as they carried out the normal tasks of living in tents and moving on foot. At Churchill, where mechanical transport and laboratory facilities were available, direct measurements with the Kofranyi-Michaelis respirometer were obtained as the personnel carried out their training assignments including cross country patrols up to 6 $km \cdot d^{-1}$. At Frobisher Bay close observation and diaries were used to assess the energy expenditures of the same personnel. A gross energy cost of 3,484 $kcal \cdot min^{-1} \cdot d^{-1}$ was calculated from these data. The ration provided 3,600 kcal, enough to maintain caloric balance although there were significant changes in body composition.

Buskirk, E. R., T. E. Dee, B. E. Welch, L. M. Levy, and G. F. Consolazio. 1957. Caloric Intake Associated with Prolonged Hard Work in the Cold. Natick, Mass.: Quartermaster Research and Development Center. Technical Report EP-58, Mar., 28 pp., illus.

Caloric intake, fluid balance, and body composition were studied in a group of 26 men during a 28-day stay at Fort Churchill, Manitoba, Canada. The first seven days were spent in a pre-bivouac situation preparing for bivouac. The remaining days were spent in the field in a moving self-sustaining bivouac. 1. During the pre-bivouac period

the caloric intake averaged 3,355 kcal·man^{-1}·d^{-1}. During the bivouac the intake was increased to 4,163 kcal·man^{-1}·d^{-1}. The latter figure may be regarded as a maximal figure for sustained (more than five days) hard work in the cold. A mean weight loss of 1.19 kg·man^{-1} was observed during the bivouac. This weight loss was accompanied by a corresponding increase in body density. 2. Water balance calculated for the bivouac indicated a negative balance of 93 g·man^{-1}·d^{-1} or 1.95 kg·man^{-1}·d^{-1} total. Deuterium oxide space gave essentially the same results. 3. Nitrogen balance data indicated some retention of nitrogen during the bivouac. 4. Although body composition changed (loss of water and fat and gain of nitrogen), this redistribution probably reflects a "beneficial" effect of the extensive work and not an inadequacy of calories.

Buskirk, E. R., J. Hodgson, and D. Blair. 1980. Assessment of daily energy balance: some observations on the methodology for indirect determinations of energy intake and expenditure. Pp. 113-117 in Assessment of Energy Metabolism in Health and Disease, J. Kinney, ed. Columbus, Ohio: Ross Laboratories.

Survey techniques have been presented for assessing daily food intake and physical activity. However, their worth is shown in the solution of practical problems related to the offering of proper nutrition and to the prevention and management of disease. Our understanding of applicability and our efforts to improve survey techniques may ultimately prove of additional value to the populace at large. It appears that such an undertaking is well worth the effort entailed, even though the current perspective is perhaps not as bright as we would like, since both methodology and the rigor with which the most applicable techniques are applied (for the intended experimental or therapeutic purpose) need to be improved. Coefficients of variation of 20 percent are probably too large for optimum use. An effort should be made to reduce CV to 10 percent or less.

Buskirk, E. R., P. F. Iampietro, and B. E. Welch. 1957. Variations in Resting Metabolism with Changes in Food, Exercise and Climate. Natick, Mass.: Quartermaster Research and Development Center. Technical Report EP-59, May, 23 pp., illus.

Basal oxygen consumption (basal VO$_2$) and resting VO$_2$ measured at 4-hour intervals were studied in groups of eight men in an attempt to describe the effects of specific dynamic action (SDA), exercise, and climate on metabolism. The elevation in VO$_2$ that occurred throughout the day was largely explained by the change in VO$_2$ associated with SDA. Moderate exercise alone did not alter resting VO$_2$. A small "diurnal" elevation in VO$_2$ occurred during fasting with or without exercise. Climate per se did not appear to influence basal VO$_2$ or the pattern of resting metabolism during the day with the exception that at 2000 hours the VO$_2$ in the hot-dry climate was

significantly higher than the 200-hours values in the other climates. Peak VO_2 associated with SDA can amount to approximately two times basal VO_2. Thus, when total VO_2 (gross oxygen consumption) is used as an expression of energy expenditure for mild or light physical work, considerable variation may result unless measurements are well controlled with respect to food intake and time after meals.

Buskirk, E. R., et al. 1956. Caloric Intake and Energy Expenditure in a Sub-Arctic Environment. Natick, Mass.: Quartermaster Research and Development Center. Technical Report EP-33, Mar., 46 pp., illus.

Caloric intake and caloric expenditure were studied in eight men during 10 days of pre-bivouac, 12 days of bivouac, and 8 days of post-bivouac. Fort Churchill, Manitoba, Canada, was the test site. Mean ambient temperatures for the three periods were $-25^{\circ}C$ $(-13^{\circ}F)$, $-31^{\circ}C$ $(-23^{\circ}F)$, and $-26^{\circ}C$ $(-15^{\circ}F)$ respectively. 1. Caloric intake averaged approximately 3,600 $kcal \cdot man^{-1} \cdot d^{-1}$ for the entire study. The men consumed 3,613, 3,644 and 3,472 kcal respectively during the pre-bivouac, bivouac and post-bivouac periods. Since a weight loss of 1.9 kg occurred during the bivouac period, an estimated correction of caloric requirement for this weight loss would increase it to 4,260 $kcal.man^{-1}.d^{-1}$. Dietary composition did not change during the three periods of the experiment. The percentage of the total energy of the average food consumed during all periods was 13.8 percent from protein, 38.5 percent from fat, and 47.7 percent from carbohydrate. 2. Energy expended during outdoor activities involving progression across the snow cover at 2.27 mph was found to average approximately 7 $kcal \cdot min^{-1} \cdot d^{-1}$ or 221 $kcal \cdot m^{-2} \cdot h^{-1}$. Thus, the men averaged 1,500 $kcal \cdot man^{-1}.d^{-1}$ for outdoor activity. Variations were noted in energy expenditure between skiing, snowshoeing and walking over the same snow cover. Snowshoeing was the most economical in this group of men. 3. A comparison was made between studies of caloric intake in Northern latitude areas. It appears that food consumption calculated by the inventory method, using standard food tables, has led to exceptionally high estimates of caloric consumption. Furthermore, it is impossible to interpret the findings of most previous studies because the daily activity level was never clearly established.

Consolazio, C. F. 1966. Nutrition variation in world populations and performance potential. Ann. N.Y. Acad. Sci. 134:885-896.

Two specific areas are discussed: nutritional status and variation in world populations, and the performance potential in man under conditions of optimal and restricted (kcal) nutrition. 1. The nutritional status of world populations is investigated in relation to nutritional deficiencies and to dietary allowances and requirements. 2. Performance potential of world populations is discussed in

relation to the normally physically fit individual, to race, to calorie restriction and rehabilitation, to salt and water requirements, and to vitamin deficiencies and subsequent supplementation.

Consolazio, C. F. 1969. Energy metabolism and extreme environments (heat, cold and high altitude). Pp. 324-327 in Proceedings of the Eighth International Congress on Nutrition, Czechoslovakia, August 28-September 5, 1969. Excerpta Medica International Congress Series 213.

The energy requirements in a cold environment are practically unchanged as compared to a temperate environment, except for the 2-5 percent increase due to the wearing of heavy clothes and footgear, providing that the individual is adequately clothed. Based on observed increases in VO_2, the daily energy requirements for men living and working in a hot environment are increased. This is related to the increased requirement of circulation in heat transport, the increased action of the sweat glands, increased caloric loss due to sweat vaporization and to the increase in body temperature.

Preliminary data indicate that the energy requirements may be unchanged at 3,475 m. On the other hand, VO_2, V_E and heart rates during standardized physical activities are significantly increased at 4,300 m. This indicates that the energy requirements at this elevation may be increased.

Consolazio, C. F. 1971. Energy expenditure studies in military populations using Kofranyi-Michaelis respirometers. Amer. J. Clin. Nutr. 24:1431-1437.

The K-M metabolimeter is now being used extensively in measuring the physical activities of military personnel. This paper describes the use of this meter, the problems of calibration and diffusion of the respiratory gases, the newer modifications for simplification of the measurements, and the total errors that are anticipated in its use. Data are presented from various military studies in which the energy cost of various physical activities have been measured and calculated in $kcal \cdot min^{-1}$.

Consolazio, C. F., H. L. Johnson, R. A. Nelson, R. Dowdy, H. J. Krzywicki, T. A. Daws, L. K. Lowry, P. P. Waring, W. K. Calhoun, B. W. Schevenneker, and J. E. Canham. 1979. The Relationship of Diet to the Performance of the Combat Soldier. Minimal Calorie Intake during Combat Patrols in a Hot Humid Environment. Presidio of San Francisco, Calif.: Letterman Army Institute of Research. Report 76; Oct., 65 pp.

Four groups of physically conditioned, heat-acclimated men consumed 585, 948, 1,362 and 3,301 $kcal \cdot d^{-1}$ for a 10-day period during

maneuvers in a jungle environment. In the three calorie-restricted groups, the body weight losses were minimal in comparison to previous laboratory studies. The loss in body weight was calculated to be primarily body fat that approximated 2.3 to 3.2% of the initial body weight and total body waters that approximated 0.6 to 2.2% of the initial body weight. The data demonstrated that nitrogen balances could not be attained on 2,362 $kcal \cdot d^{-1}$ under the conditions of this study. No significant differences were observed in the results of physiological work capability in the experimental period when comparing them to the control values. Under the conditions of this study, it is suggested that with fairly heavy physical activity, an intake of greater than 1,360 $kcal \cdot d^{-1}$, containing an adequate intake of minerals and water, is necessary to prevent a negative nitrogen balance but an intake of 1,360 $kcal \cdot d^{-1}$ will prevent loss of physiological work performance in men for short periods of time of up to 10 days.

Consolazio, C. F., F. Konishi, R. V. Ciccolini, J. M. Jamison, E. J. Sheehan, and W. F. Steffen. 1960. Food consumption of military personnel performing light activities in a hot desert environment. Metab. Clin. Exp. 9:435-442.

Food consumption was measured on two groups (a headquarters group and a military police company) of military personnel engaged in light activity occupations and living in a hot desert environment (Yuma, Ariz.). Food consumed in the mess was determined by weighing and chemical analysis of food served less plate waste. Questionnaires were used to determine the amount of food the subjects ate outside of the mess. Over a 14-day period, the total food consumption from all sources, when corrected for body weight changes, averaged 4,061 kcal for the headquarters group, who maintained their body weight, and 4,532 kcal for the military police, who lost an average of 17 $g \cdot man^{-1} \cdot d^{-1}$, equivalent to 116 kcal. The consumption of food was in the same high range as that of military personnel performing hard physical labor in a temperate or subarctic environment. These values are considerably higher than the 3,069 kcal that would be calculated for light activity at the prevailing temperature according to the formula recommended by the National Research Council's Committee on Dietary Allowances and the Food Agriculture Organization of the United Nations. The high food intake observed in this study may be related to the hours of exposure to direct sunlight and outdoor heat, the rate of sweating, and the increased body temperature of personnel exposed to a hot environment, all of which increase energy requirements.

Consolazio, C. F., L. O. Matoush, H. L. Johnson, H. J. Krzywicki, T. A. Daws, and G. J. Isaac. 1969. Effects of high-carbohydrate diets on performance and clinical symptomatology after rapid ascent to high altitude. Fed. Proc. 28:937-943.

Two groups of men consumed liquid diets of constant nutrient composition for 27 consecutive days, including 8 days of sea level control, 12 days of altitude exposure to 4,300 m, and 7 days of rehabilitation at sea level. One group, a control, consumed a diet with a normal distribution of nutrients, and the second consumed a diet high in carbohydrate (68%) and low in fat (20% of the kcal). The data suggest that liquid diets fed during prior heavy physical activity at sea level may be beneficial in reducing the clinical symptomatology observed during rapid ascent to high altitudes. It also appeared that the high carbohydrate-low fat diet greatly reduced the clinical symptoms at altitude over the control group. Significant increases were observed at altitude over control values for V_EBTPS in $L.min^{-1}$, $VO_2ml \cdot kg^{-1}$ per min, pulse, and respiration rates. Although there appeared to be no differences between groups at altitude in three of the four standardized work measurements, the men in the high-carbohydrate group showed considerably better performance in the heaviest work at altitude. This group more than doubled the duration of work on the treadmill, 9.6 versus 4.6 min. The VO_2's in $ml \cdot kg^{-1} \cdot min^{-1}$ were all significantly increased at altitude for both groups during the four work measurements, suggesting that the energy requirements may be increased at high altitude.

Consolazio, C. F., L. O. Matoush, H. L. Johnson, H. J. Krzywicki, G. J. Isaac, and N. F. Witt. 1968. Metabolic aspects of calorie restriction: hypohydration effects on body weight and blood parameters. Amer. J. Clin. Nutr. 21:793-802.

In this study a group of 8 men consumed 420 $kcal \cdot d^{-1}$ for 10 days with a daily energy expenditure of 3,200 $kcal \cdot d^{-1}$. It was observed that limited calories without mineral supplementation appeared to be more beneficial than complete starvation. Some major abnormalities were still present including fairly large body water losses during days 1 and 2, significant protein losses, and abnormal EEG patterns in all men in group 1 during calorie restriction. The EEGs from all of these men were normal within 2 days on return to a normal dietary intake. Mineral supplementation with limited carbohydrate calories had beneficial effects in reducing water deficits and hypohydration, preventing ketosis, and preventing abnormal electroencephalogram tracings.

Consolazio, C. F., L. O. Matoush, R. A. Nelson, J. B. Torres, and G. J. Isaac. 1963. Environmental temperature and energy expenditures. J. Appl. Physiol. 18:65-68.

Metabolic rates were compared of seven young men performing three levels of physical activity at three environmental temperatures of 21.1, 29.5, 37.8°C (70, 85, and 100°F). This study indicates that as the environmental temperature increases there is also an increase in metabolic rate of men performing a fixed activity. It has been

shown that there was a significantly higher metabolic rate for men
working at 100°F than at 85°F and 70°F. These increases
averaged 11.4% for the heavier activity. Body temperatures also were
significantly higher at 100°F than at 85°F and 70°F environments
(P < .005). They averaged 99.6°F at the 100°F temperature, and
99.1°F for both the 85°F and 70°F temperatures. The findings in
this study indicate that the metabolic rate of a fixed physical
activity is increased in the heat and that this increase is not due to
acclimatization or training.

Consolazio, C. F., R. A. Nelson, H. L. Johnson, L. O. Matoush,
    H. J. Krzywicki, and G. J. Isaac. 1967. Metabolic aspects of
    acute starvation in normal humans: performance and cardiovascular
    evaluation. Amer. J. Clin. Nutr. 20:684-693.

In a combat or combat patrol situation of nonresupply for periods
as long as 10 days, the individual soldier must carry his full field
equipment and an adequate supply of food and water. There has been
some question as to the minimal food intake necessary to permit the
combat soldier on patrol to maintain maximal physical and mental
performance. In the first paper of this series...data were presented
for six healthy adults studied during a 10-day fast without mineral
supplementation. The major problems encountered were a) highly
negative water balance (approximately 500 $g \cdot d^{-1}$), resulting in
body hypohydration; b) the large negative nitrogen balances (8.5
$g \cdot d^{-1}$), showing that body protein was being catabolized; and c)
the large mineral losses (1.85 g of sodium and 1.5 g of
potassium/day). Since these factors could eventually lead to both
physical and mental inefficiency, fasting without mineral
supplementation could not be recommended for troops on combat patrol.

Consolazio, C. F., R. A. Nelson, L. O. Matoush, and J. E. Hansen.
    1966. Energy metabolism at high altitude (3,475 m). J. Appl.
    Physiol. 21:1732-1740.

Maximal work capacity (VO_2) on the bicycle ergometer was
decreased in three groups of men, one group acclimated to sea level,
and two groups acclimated to 1,610 m. At 3,475 m, maximal VO_2 in
milliliters per kilogram body weight per minute was reduced by 17% for
the sea-level group, and by 10% for the group from 1,610 m. Although
there was a difference of approximately 7% in VO_2 between sea level
and 1,610 m, there was no measurable beneficial effect of
acclimatization at 1,610 m in improving maximal work at 3,475 m.
Maximal work capacity and maximal VO_2 did   improve over a 20-day
period at altitude. V_ESTPD was decreased, and V_EBTPS increased on
arrival at altitude with a gradual increase in both during prolonged
exposure. Pulse rates at rest and during moderate exercise were
consistently high at high altitudes, whereas the maximal pulse rates
gradually declined. Oxygen consumption at the basal, sitting rest,

and moderate exercise states were not markedly changed by altitude. The physiological cause for the cessation of maximal work at altitude remains obscure. Under the conditions of this study, a) the 1,610-m elevation did not seem to be beneficial in improving the maximal work at 3,475 m, b) a 20-day acclimatization period at 3,475 m did not result in a superior submaximal or maximal work performance on return to sea level, and c) individuals can adequately perform submaximal work even after the initial high-altitude exposure.

Consolazio, C. F., R. Shapiro, J. E. Masterson, and P. S. L. McKinzie. 1961. Energy requirements of men in extreme heat. J. Nutr. 73:126-134.

A study was performed in extreme heat on 8 healthy young adults for three consecutive 10-day periods. In period 1, day-time temperatures in the hot sun averaged 40.5°C; in period 2, in the hot shade, 40.3°C; and in period 3, in the cool shade, 26.0°C. The men carried on constant daily activity, and were allowed food and water ad libitum.

1. With the set conditions of this study, the data suggest that there is an increased caloric requirement for men working and living in extreme heat. Significant increases were observed in food consumption and the actual caloric requirements were even greater because of changes in the body composition of the men.

2. The differences in energy cost of the various resting and exercise activities, when comparing the hot-sun or hot-shade to the cool-shade phase, were significant.

3. Energy requirements averaged 55.5, 56.4, and 36.6 $kcal \cdot kg^{-1}$ of body weight, when corrected for body composition changes.

4. These increased requirements are probably due to the increased heat load imposed on the body by solar radiation and extreme heat. The increased requirements reflect, in all likelihood, a combination of increased action of the blood in heat transport, increased action of the sweat glands, and the increased total metabolic rate due to the elevation in body temperature.

Cymerman, A., K. B. Pandolf, A. J. Yound, and J. T. Maher. Energy expenditure during load carriage at high altitude. 1981. J. Appl. Physiol.: Respirat. Environ. Exer. Physiol. 51(1):14-18.

To determine the applicability of a prediction equation for energy expenditure during load carriage at high altitude that was previously validated at sea level, oxygen uptake (VO_2) was determined in five young men at 4,300 m while they walked with backpack loads of 0, 15, and 30 kg at treadmill grades of 0, 8 and 16 percent at 1.12 $m \cdot s^{-1}$ for 10 min. Mean $\pm$ SE maximal VO_2, determined on the cycle ergometer, was 42.2 $\pm$ 2.3 at sea level and 35.6 $\pm$ 1.7 $ml \cdot kg^{-1}$ at altitude. There were no significant differences in daily VO_2 at any

specific exercise intensity on days 1, 5, and 9 of exposure, nor were
there any differences in endurance times at the two most difficult
exercise intensities. Endurance times for 15- and 30-kg loads at 16%
grade were 7.3 and 4.2 min, respectively. Measured energy expenditure
was compared with that predicted by the formula of Pandolf et al. (J.
Appl. Physiol.: Respirat. Environ. Exercise Physiol. 43:577-581) and
found to be significantly different. The differences could be
attributed to measurements at metabolic rates exceeding 730 W or 2.1
$L.O_2.min^{-1}$ used at altitude for exercise intensities not exceeding
this upper limit. The observed deviations from predicted values at
the high exercise intensities could possibly be attributed to the
occurrence of appreciable oxygen deficits and the inability to achieve
steady-state conditions.

Daniels, F., Jr., and R. Madden. 1950. Energy Expenditure during Some
    Sub-Arctic Bivouac Activities. Natick, Mass.: Quartermaster
    Research and Development Center. Technical Report EP-20, Apr., 17
    pp.

The energy cost for the performance of certain activities was
measured at Fort Churchill, Canada. The energy costs varied from
about 40 $kcal·m^{-2}·h^{-1}$ (in sleeping bag at night) to about 325
$kcal·m^{-2}·h^{-1}$ (simulated infantry assault), an eight-fold
increase. Other activities, such as cutting snow blocks, chopping
ice, pitching tents, etc., were also measured and the energy costs
were in the range 200 to 300 $kcal·m^{-2}·h^{-1}$.

Evans, W. J., F. R. Winsmann, K. B. Pandolf, and R. F. Goldman.
    1980. Self-paced hard work comparing men and women. Ergonomics
    23:613-621.

Six fit male subjects (23 years, 171 cm, 67 kg, maximal VO_2 50.3
$ml·kg^{-1}·min^{-1}$) and six fit female subjects (22 years, 163 cm, 57
kg, maximal VO_2 41.1 $ml·kg^{-1}·min^{-1}$) performed self-paced hard
work while walking over four different terrains carrying no external
load, 10 kg, and 20 kg. Time on each course for individual subjects
was used to determine speed and energy expenditure; heart rate was
recorded as each subject completed each course. Walking speed and
energy expenditure of the males were found to be significantly greater
(p < 0.05) than those of the females over all terrains (blacktop road,
1.6 km; dirt road, 1.8 km; light brush, 1.4 km; and heavy brush, 1.3
km) and for each load carriage condition. Relative energy
expenditures of the males and females for all conditions were very
similar (p > 0.05) and remarkably constant at a value close to 45%
VO_2 max. These data indicate that the voluntary hard work rate is
dependent upon maximal aerobic power. The best predictor of speed for
self-paced hard work of males and females for 1 to 2 hours in duration
appears to be based on 45% of maximal aerobic power.

Friedemann, T. E., H. F. Kraybill, and C. F. Consolazio. The use
of recommended dietary allowances in military nutrition. 1959.
Am. J. Pub. Hlth. 49:1006-1012.

The feeding of U. S. Army personnel is planned in accordance with
minimal dietary standards which are based upon the recommended dietary
allowances of the Food and Nutrition Board of the National Research
Council, as modified by the special requirements of troops under
various operational conditions. The Army basic standard prescribes
the minimum intake of the physically active soldier in a temperate
climate as: 3,600 kcal, 100 g protein, 700 mg calcium, 5,000 I.U.
vitamin A, 75 mg riboflavin, and 16 mg niacin. The Master Menu, which
is used throughout the Army for procurement and serving of food, is
planned to yield these nutrients. During 1957 the average edible
nutrients provided by the Master Menu were about: 4,195 kcal, 131 g
protein, 199 g fat, and 470 g carbohydrate. The vitamins and minerals
were well above the recommended minimal intake. In surveys conducted
in four training camps the average of nutrients consumed in the mess
and from other sources was: 4,265 kcal, 1o. g protein, 201 g fat, and
484 g carbohydrate. These results agree closely with the total edible
nutrients provided by the Master Menu. The average caloric
requirement for maintenance of weight in these very active young
soldiers was 4,066 kcal; the average for moderately active soldiers
was 3,175 kcal. The history of military nutrition from 1775 to date
and the factors which contributed to changes in the Army diet during
those years are briefly reviewed.

Givoni, B., and R. F. Goldman. 1971. Predicting metabolic energy
cost. J. Appl. Physiol. 30:429-433.

Supplementing data from this laboratory on the energy costs of
level or grade walking, with and without loads, with data from the
literature, an empirical equation has been prepared for the prediction
of the metabolic costs of such activities. The equation has been
examined and found to be valid for walking speeds from 2.55 to 9
$km \cdot h^{-1}$ with grades up to 25% and running speeds from 8 to 17
$km \cdot h^{-1}$ with grades up to 10% with loads up to 70 kg. Modifying
coefficients are suggested for terrains other than treadmill walking,
for load placement, and for very heavy levels of work. The
correlation between predicted and measured energy costs is usually
0.95 or greater; the mean standard error of estimate over all
conditions is 29 $kcal \cdot h^{-1}$. The equation also appears valid when
the subject is free to choose his own progression rate.

$$M = n(W + L)(2.3 + 0.32 [V - 2.5]^{1.65}$$

$$+ G[0.2 + 0.07 (V - 2.5)]) \quad (1)$$

where:

M = metabolic rate, $kcal \cdot h^{-1}$
n = terrain factor, defined as 1 for treadmill walking
W = body weight, kg
L = external load, kg
V = walking speed, $km \cdot h^{-1}$
G = slope (grade), %.

Goldman, R. F. 1965. Energy expenditure of soldiers performing combat type activities. Ergonomics 8:321-327.

The energy cost of a number of tactical tasks was measured for soldiers during actually controlled rather than experimentally controlled tasks. The upper range of energy expenditure rates was 400 to 450 $kcal \cdot h^{-1}$ during these tactical maneuvers; incipient physical or heat exhaustion was associated with the few much higher values. The realism of the tactical situation, and an estimate of the contribution made by the heat load and wearing of the gas mask to the energy costs measured is presented. The hypothesis is presented that the upper range of energy expenditure rates for prolonged periods is independent of terrain when men are allowed to work at their own pace, but depends on the total weight carried. The relationship between ventilation volume and energy expenditure in this study is compared with data presented by Liddell and suports the argument that calculation of energy expenditure can be reliably made using a single formula to concert ventilation volume per se, particularly within the practical accuracy of field measurments.

Goldman, R. F. 1980. Effect of environment on metabolism. Pp. 117-122 in Assessment of Energy Metabolism in Health and Disease. J. Kinney, ed. Columbus, Ohio: Ross Laboratories.

It seems appropriate to dissect any attempt to evaluate environmental effects into three distinct areas of metabolic responses: 1) Changes in BMR, in a thermoneutral environment, should reflect only effects of adaptations by the body tissues in response to the various stresses of an environment, 2) Changes in resting metabolic rate, in the environment in question, should also reflect direct thermal effects on the body. 3) Changes in metabolic rate during work might well mask such adaptation and/or direct thermal effects, while revealing mechanical effects associated with the environment.

Goldman, R. F., and P. F. Iampietro. 1962. Energy cost of load carriage. J. Appl. Physiol. 17:765-676.

The relative contributions of rate of progression (1.5-4.0 mph) grade 13.9', and load (10-30 kg) to total energy cost were

determined. The data obtained were integrated graphically with some of the available energy cost data in the literature to provide a useful graph for estimating energy expenditure. It was tentatively concluded that for grade walking over the ranges studied, the energy cost per unit weight is essentially the same whether the weight is of the body or the load.

Grande, F., J. T. Anderson, and A. Keys. 1958. Changes of basal metabolic rate in man in semistarvation and refeeding. J. Appl. Physiol. 12:230-238.

Basal heat production (BMR), total body water, extracellular fluid space and nitrogen balance were measured in 25 normal young men during control, semistarvation and recovery, in two experiments referred to as "54" and "55". A normal diet was given during control and recovery. In semistarvation the diet consisted of carbohydrate plus a daily supplement of 4.5 g NaCl and vitamins. The 13 men in 54 received daily 3,280, 1,010 and 5,300 kcal during these periods and those (12) in 55 3,966, 1,000 and 5,384 kcal. Physical activity, including treadmill walking costing about 1,200 kcal daily during control, was constant throughout. "Cells" was computed as gross weight less fat, extracellular fluid and bone mineral. The gross BMR decreased in all the subjects during semistarvation, the average decline being 17.1% after 19 days (54) and 21.4% after 13 days (55). The BMR was also decreased when computed per unit for gross weight, per unit of body surface, per unit of gross body weight to the 0.73 power and per unit of "cells." The average percentage decline being, respectively, 8.7, 13.4, 9.8 and 11.8 for experiment 54 and 14.2, 18.4, 15.9 and 16.6 for experiment 55. All P values for the differences are < 0.001. After 1 week of refeeding the gross BMR returned precisely to the control value in each group and remained at that level until the end of the observations.

Gray, E. L., C. F. Consolazio, and R. M. Kark. 1951. Nutritional requirements for men at work in cold, temperate and hot environments. J. Appl. Physiol. 4:270.

The caloric ouptut of men doing hard work was measured in three different environments. They wore standard arctic, temperate and desert clothing. The subjects were healthy university students in excellent training. Their daily dietary intake exceeded the National Research Council's Recommended Daily Allowance for protein, calcium, phosphorus, iron, vitamin A, thiamin, riboflavin, niacin and ascorbic acid. Their protein intake was largely of animal origin and their caloric intake was equal to their needs. Besides daily observations on general health, dietary intake, body weight and extra-curricular activities of the subjects, measurements of basal metabolic rate, work output, oxygen consumption at work and during exercise and differences in body weight before and after exercise were made. The subjects were

trained for 3 weeks to standardize their work outputs before making the final measurements. Work in the 3 simulated climates consisted of alternating bicycle ergometer riding with climbing over a standard obstacle. All movements during work were made in a standard manner to a definite cadence. The results obtained showed: a) that the caloric output for a given amount of external work performed at a constant temperature increased about 5% when the clothing was changed from desert clothing to temperature clothing and increased about 5% more when the clothing was changed from temperate to arctic clothing; b) that the caloric output for a given amount of external work performed in a given outfit of clothes decreased about 2% as the temperature was raised from $-15°$ to $+60°F$ and decreased about 2% more when the temperature was raised from 60 to $90°F$.

Haisman, M. F., and R. F. Goldman. 1974. Effect of terrain on the energy cost of walking with back loads and handcart loads. J. Appl. Physiol. 36:545-548.

Previous work established that moving heavy loads by cart on a smooth surface required a lower energy cost than the same load on the back. However, the effect of uneven terrain on this energy cost differential had not to our knowledge been studied systematically. Eight young soldiers carried a 20-kg back load (additional to clothing and respirometer) or pulled a handcart weighing 20, 60, or 100 kg, at two speeds (0.89 or 1.34 $m \cdot s^{-1}$) on three terrains (blacktop road, dirt road, or grassland) in a randomized factorial design. Energy cost was measured three times during each 30-min walk. The results indicated that although on a smooth surface the 100-kg cart is no more costly than a 20-kg backpack, on both uneven terrains only the 20-kg cart was equivalent to a 20-kg back load. Nonetheless, the energy cost of moving the 100-kg cart over these uneven terrains, at these speeds, was within acceptable physiological limits for these subjects, although this would probably not be the case with more difficult terrains such as soft sand or heavy brush.

Hansen, J. E., J. A. Vogel, G. P. Stelter, and C. F. Consolazio. 1967. Oxygen uptake in man during exhaustive work at sea level and high altitude. J. Appl. Physiol. 23:511-522.

Oxygen intake (VO_2) was measured in 16 healthy soldier volunteers at sea level and 4,300 m (Pikes Peak) before, during, and after exercise on the bicycle ergometer. VO_2's at 4,300 m were similar to sea-level values at rest and during mild and moderate exercise. Mean maximum VO_2 at 4,300 was 83% of sea-level value and was unaffected by rate of ascent. Resting and exercise ventilations increased at 4,300 m first by a rise in breathing frequencies and later by an increase in tidal volumes. During increasing exercise at 4,300 m, the alveolar-arterial difference for oxygen increased more than at sea level and the oxygen saturation of arterial blood decreased. During

maximum work the oxygen saturation of mixed venous blood did not decline to sea-level values. Total work until exhaustion did not improve after 2 weeks at 4,300 m despite rising in maximum exercise ventilation and oxygen content of arterial blood. Physical training at 4,300 m was of no greater value than similar training at sea level in increasing sea-level maximum VO_2.

Hughes, A. L., and R. F. Goldman. 1970. Energy cost of 'hard work.' J. Appl. Physiol. 29:570-572.

The hypothesis that while working hard, men carrying a load will voluntarily adjust their rate of progression to work at energy expenditures of 425 kcal·h^{-1} ± 10% was tested. Twelve men volunteers carried loads ranging from 0 to 60 kg on a treadmill designed to allow imperceptible, automatic adjustments to self-paced rate of progression. The results indicated that the rate of progression decreased almost linearly with increasing load. Energy cost per kilogram meter was lowest when the load carried was 30 to 40 kg, indicating greatest economy when carrying these loads. It was thus suggested that maximum efficiency while carrying a load can be obtained when walking at a comfortable speed (5 km·h^{-1}), with a load weighing 30-40% of body weight.

Iampietro, P. F., E. R. Buskirk, and D. E. Bass. 1957. Caloric Intake During Prolonged Cold Exposure. Natick, Mass.: Quartermaster Research and Engineering Center. Technical Report EP-66, Sept., 10 pp., illus.

The effects of continuous cold stress on caloric intake and energy expenditure of five men were studied. Cold stress consisted of living in a chamber at 60°F (15.6°C) for 14 days. The men wore only shorts and were allowed minimal physical activity. The cold period was preceded and followed by two weeks at 80°F (26.7°C). Activity and dietary composition were the same for all periods. During the control and recovery periods caloric intake averaged 2,287 and 2,405 kcal·man·d^{-1} and weight loss averaged 1.75 and 0.90 kg·man^{-1} respectively. During the cold period caloric intake was 2,870 kcal·man^{-1}·d^{-1}; there was no weight loss for this period. When corrected for weight loss, caloric intakes averaged 2,661 and 2,678 kcal·man^{-1}·d^{-1} for the control and recovery periods, respectively. An increase in resting energy expenditure of about 140 kcal·man^{-1} per daytime-hours was observed in the cold period. The increased caloric intake in the cold was associated with an increased energy expenditure due to non-dectectable shivering and occasional frank shivering. There was no evidence that cold stress imposed additional caloric requirements apart from those resulting from increased muscle activity.

Iampietro, P. F., E. R. Buskirk, D. E. Bass, and B. E. Welch. 1957. Effect of food, climate and exercise on rectal temperature during the day. J. Appl. Physiol. 11:349-352.

A series of experiments were performed to determine the effect of climate, food intake and activity level on the diurnal pattern of rectal temperature (T_r) from 8 a.m. to 8 p.m. The results indicate that living in diverse climates has little or no effect on the diurnal pattern of T_r. Activity level, when food intake was adequate, did not alter the pattern. Fasting, with no exercise, reduced the diurnal elevation to one-half the "normal" elevation. During fasting with exercise the rectal temperature at 8 p.m. was the same as the value at 8 a.m. (i.e., no diurnal increase was evident). Thus, the major portion of the diurnal change occurring between 8 a.m. and 8 p.m. was associated with the ingestion of food.

Iampietro, P. F., and R. F. Goldman. 1962. Prediction of Energy Cost of Treadmill Work. Oklahoma City, Okla.: Federal Aviation Agency. Report 62-5, Apr., 4 pp.

The relative contributions of rate of progression (1.5 to 4.0 mph), grade (4 to 9%), and load (10 to 30 kg), to the total energy cost of treadmill work were determined. The data obtained were integrated graphically with some of the available energy cost data in the literature. A useful graph is provided for estimating energy expenditure. It was tentatively concluded that for grade walking over the ranges studied, the energy cost per unit weight is essentially the same whether the weight is of the body or the load. The data are useful in that a correlation between the diverse literature reports on treadmill studies using different speeds and loads is made feasible.

Iampietro, P. F., M. Mager, R. F. Goldman, and D. E. Bass. 1961a. Composition and Caloric Density of Weight Loss During Caloric Restriction in the Cold. Natick, Mass.: Quartermaster Research and Engineering Center. Technical Report EP-156, 6 pp.

The simplest method for determining the amount of food a soldier requires is to provide him with sufficient food to maintain a constant weight and to measure the kcal consumed. Many of the established requirements for kcal have been derived from this simple approach. When, however, a loss in weight occurs despite more than adequate availability of food, calculations must be made of the kcal which the body itself has supplied in terms of tissue breakdown and the final estimate of kcal requirements must be corrected accordingly. Such corrections require a rather precise knowledge of how many kcal the body tissues have provided, i.e., the kcal density of the weight loss. The present report provides values which may be used for this purpose with reasonable confidence.

Iampietro, P. F., M. Mager, R. F. Goldman, and D. E. Bass. 1961b.
Composition and caloric density of weight loss during caloric
restriction in the cold. J. Appl. Physiol. 16:624-626.

Two groups of 6 men each lived for 14 days in a cold chamber at
$60^{\circ}F$ (15.6°C); activity was sedentary and only athletic shorts
were worn. During this period one group (A) was semi-starved (600
$kcal.d^{-1}$). Changes in body composition were measured and caloric
density of weight loss was calculated. Mean weight loss was 5.66 kg
for A, and 8.56 kg for B. Composition and caloric density of weight
loss were almost identical for both groups. Composition of weight
loss with regard to fat, protein, and water was: 39, 10, and 51% for
A; 39, 11, and 49% for B. Caloric density was 3.91 $kcal \cdot g^{-1}$ for A
and 4.06 $kcal \cdot g^{-1}$ for B.

	Group	
	A	B
Total Weight Loss (kg)	5.66	8.56
(A) Protein (kg)	0.52	0.96
(B) Fat (kg)	2.15	3.31
Caloric Equivalent of Protein (kcal)	2,136	3,944
Caloric Equivalent of Fat (kcal)	19,995	30,783
Total Calories	22,131	34,727
Caloric Density of Weight Loss ($kcal \cdot g^{-1}$)	4.91	4.06

Iampietro, P. F., J. A. Vaughan, A. R. MacLeod, B. E. Welch,
J. G. Marcinek, J. B. Mann, M. P. Grotheer, and T. E. Friedeman.
1956. Caloric intake and energy expenditure of 11 men in a desert
environment. Natick, Mass.: Quartermaster Research and
Development Center. Technical Report EP-40, Oct., 24 pp., illus.

Caloric intake and expenditure were studied in 11 men during a
sojourn in the hot-dry environment found at Yuma, AZ. The mean
ambient temperature was 33°C (91°F) and the mean relative humidity
was 35%.

1. Caloric intake averaged 2,857 $kcal \cdot man^{-1} \cdot d^{-1}$ during the
study. When caloric intake was corrected for the caloric equivalent
of body weight loss (0.102 $kg \cdot man^{-1} \cdot d^{-1}$), the average intake was
increased to either 3,311 $kcal \cdot d^{-1}$ or 2,878 $kcal \cdot d^{-1}$,
depending on whether the correction for change in body fat was based
on skinfold thickness data or on body water data.
2. The dietary composition of the food (percent of kcal) was 12.5%
protein, 35.5% fat and 52.0% carbohydrate.
3. Energy expended during the 24-hour period (marching and other
activities) average 2,977 $kcal \cdot man^{-1} \cdot d^{-1}$.

Johnson, H. L., C. F. Consolazio, H. J. Krzywicki, G. J. Isaac,
and N. F. Witt. 1971. Metabolic aspects of caloric restriction:
nutrient balances with 500 kilocalorie intakes. Am. J. Clin. Nutr.
24:913-923.

Eight young, healthy adults were assigned to two groups during this
study, which was divided into three phases: a) control, 8 days on a
3,700-kcal liquid diet; b) restriction, 10 days on 500 kcal of
carbohydrate and protein, with one-half of the men (group II)
receiving mineral supplementation; and c) rehabilitation, 8 days on
the control diet. Energy expenditure was maintained at about 3,600
$kcal \cdot d^{-1}$. Body weight losses averaged 6.0 and 5.2 kg (8.1 and
7.2% of their initial weights) for groups I and II, respectively.
Some hypohydration occurred during the first days of restriction, but
part of this water was regained during rehabilitation. Under the
conditions of this study, the caloric deficit was accounted for
primarily through catabolism of fat stores, with body protein
contributing 4 to 5%. Due to the lower caloric value of protein and
its associated water, this protein loss accounted for approximately
one-fourth of the weight loss observed. Negative nitrogen balances
averaged 7.1 and 6.5 $g \cdot man^{-1} \cdot d^{-1}$, and no improvement in nitrogen
balances was observed during the study, which would indicate that this
may be the best balance attainable under these conditions. Sodium
losses amounted to only approximately 5 $g \cdot man^{-1}$ for all of the
subjects during 10 days of restriction, but potassium losses were
large, namely, 19 and 21 $g \cdot man^{-1}$ for groups I and II.

Johnson, H. L., H. J. Krzywicki, J. E. Canham, J. H. Skala,
T. A. Daws, R. A. Nelson, C. F. Consolazio, and P. P. Waring.
1976. Evaluation of Calorie Requirements for Ranger Training at
Fort Benning, Georgia. Presidio of San Francisco, Calif.:
Letterman Army Institute of Research. Report 34, 48 pp.

1. Ranger trainees showed large losses of body weight during
portions of an 8 week training cycle.
2. Average decrease in body weight was 9.4%, 57% of which was fat.
3. Nutritional stresses included: decreased hematocrit, serum
iron, transferrin saturation, serum proteins, serum potassium and
phosphorous, and an increase in urinary specific gravity.
4. An initial decrement of 10 to 15% in physical performance
capacities.
5. Recommendations: a 10 to 15% increase in rations during
specific portions of the training cycle.

Johnson, R. E. 1963. Caloric requirements under adverse
environmental conditions. Fed. Proc. 22:1439-1446.

A discussion concerning the determination of calorie requireme.ts of a healthy young man in a closed system in "zero" gravity, performing moderate level work. The following recommendations were made: (1) the goal for daily caloric content: 2,000 kcal (15% 1st class protein, 50% carbohydrate, and 35% fat); (2) water allowance: 3 $L \cdot d^{-1}$ in hot weather, 1 $L \cdot d^{-1}$ otherwise; (3) osmotic intake of 700 mosmoles$\cdot d^{-1}$ from protein and minerals. These observations constitute what might be considered a minimal approach to the solution of food and nutritional problems in prolonged space travel.

Johnson, R. E., and F. Sargent, II. 1958. Some quantitative interrelationships among thermal environment, human metabolism, and nutrition. Proc. Nutr. Soc. 17:179-186.

When a healthy man is exposed to an environmental extreme, to restriction of water, and to caloric deprivation, all at the same time, dramatic changes may occur in the efficiency of the body as a whole, and in the function of individual organs and systems. Important work has been published in this country and abroad on this "survival problem," especially on two important aspects: environmental protection and the nutritional physiology of men living on survival rations. We shall not attempt to summarize comprehensively the work of others, but will confine the presentation to a few quantitative generalizations on metabolic phenomena, arising largely from our own studies. Details of methods, complete data on clinical, biochemical, physiological and nutritional observations, and practical applications for emergency feeding are to be found in four technical military reports (Sargent, Sargent, Johnson and Stolpe, 1954, 1955; Sargent, Sargent and Johnson, 1957; Sargent and Johnson, 1958). Relationships developed include: water requirements in relation to environmental temperature and workload, daily kcal requirement in relation to environmental temperature and workload, interaction of the specific dynamic effect of food and environmental temperature.

Kark, R. M., R. R. M. Croome, J. Cawthorpe, D. M. Bell, A. Bryans, R. J. Macbeth, R. E. Johnson, F. C. Consolazio, J. L. Poulin, F. H. L. Taylor, and R. C. Cogswell. 1948. Observations on a mobile Arctic force. The health, physical fitness and nutrition of Exercise "Musk Ox," February-May 1945. J. Appl. Physiol. 1:73.

1. Observations have been made on the general health, fitness and nutritional state of members of the Canadian Army Arctic Operation "Musk Ox," February-May 1946. This was a motorized, air-supplied 3,400-mile journey in the winter through the Canadian barren lands.
2. Observations at the beginning and near the end included: a) environmental, medical and dietary histories; b) physical examinations, c) chemical determinations of important constituents of the blood and urine with the aid of an air-borne mobile laboratory;

and d) tests of physical fitness for hard muscular work. In addition, estimates of food consumption and wastage were made from records of food supplied and from dietary histories. One medical observer travelled with the force throughout the journey.

3. General health, fitness and good nutritional state were well maintained. There was no statistically significant change in average body weight. Values for hemoglobin, serum chloride, rate of excretion of chloride serum protein, serum albumin, serum globulin, serum nonprotein nitrogen, albumin globulin ratio, urine volume, ascorbic acid in the serum, urinary excretion of ascorbic acid, thiamine, riboflavin and N^1-methylnicotinamide were all within limits found in healthy well-fed white troops in other environments. Scores in tests of physical fitness showed no statistically significant change, being good at the beginning as well as near the end.

4. On the basis of clinical findings and biochemistry no cases were seen of nutritional deficiency syndromes. Of the common classical diseases and hazards reported from previous Arctic travels, only carbon monoxide poisoning occurred.

5. The calculated average daily intake of nutrients was: 4,400 kcal, 120 g protein, two-thirds animal; 520 g carbohydrate; 190 g fat; 4,900 I.U. vitamin A; 2.2 mg thiamine; 2.8 mg riboflavin; 26 mg niacin; and 50 mg ascorbic acid. This proved adequate for the needs of the operation and was provided in the form of fresh and packaged foods, ample allowance being made for wastage.

6. During the journey there was a statistically significant increase in the incidence of certain minor lesions of the skin, lips and mouth. In our opinion, these changes were not associated with disease or nutritional deficiency, but rather were the result of exposure to such environmental stresses as wind, cold and sun and to inadequate facilities for usual personal hygiene.

7. Small but statistically significant changes in chlorides, protein and ascorbic acid occurred. These are interpreted to be associated with processes of acclimatization.

8. Increases in hourly fasting urine nitrogen, phosphorus and creatinine were found; four subjects developed creatinuria during the journey.

Keys, A., H. L. Taylor, and J. Brozek. 1956a. Nutrition and Performance Capacity. Chicago, Ill.: Research and Development Command, Quartermaster Corps, U. S. Army. File N-1125, Report 7, Appendix 1, 35 pp.

The effects of maintenance on low-calorie carbohydrate diets were examined in reference to selected morphological, physiological, and psychological characteristics. This report deals with changes in body dimensions and body weight observed in two experiments. In experiment "53," 6 men were maintained on 58 kcal·d^{-1} for 12 days. In experiment "54," 13 men received daily 1,010 kcal for 24 days. Water was available ad libitum. Body weight decreased by a

total of 5.9 kg in "53" and 7.6 kg in "54." Limb and trunk
circumference exhibited significant decrements during restriction
(experiment "54"). In recovery the abdominal circumference showed the
largest gain (90% versus 40% for the upper arm). Skinfold
measurements and soft-tissue roentgenograms indicated a reduction of
30 to 40% in the thickness of the subcutaneous fat layer. Substantial
differences in gain were observed at different sites. By comparing
the negative energy balance with the weight loss, differences in the
caloric equivalent of the loss were demonstrated, from about 3,000
kcal·kg during the first three days in "53" and "54" experiments to
8,700 kcal·kg for the last three days in "54." These data, together
with estimates of the composition of the loss derived from energy
balance and nitrogen excretion, indicate that a large part of the
early weight loss must be due to water. During recovery a greater
absolute weight gain and a greater share of water in this gain was
observed in the first few days of refeeding.

Keys, A., H. L. Taylor, and J. Brozek. 1956b. Nutrition and
   Performance Capacity. Chicago, Ill.: Research and Development
   Command, Quartermaster Corps, U.S. Army. File N-1125, Report 7,
   Appendix 2, 30 pp.

The effect of caloric deficits was studied on performance capacity
under the following conditions: (1) 3,100 kcal·d^{-1} for entire
experiment (control group of 6 men); (2) 580 kcal·d^{-1} for 12 days
(6 men); (3) 1,010 kcal·d^{-1} for 24 days (13 men). Except for the
control group, all men ate a diet of pure carbohydrate and 4.5 g of
NaCl daily during the period of caloric restriction. Assigned work
requiring 1,200 kcal·d^{-1} was performed by each subject in both
experiments. The 580 kcal·d^{-1} prevented ketosis and demonstrable
liver damage but failed to maintain adequate work blood sugar levels.
The capacity to perform both aerobic and anaerobic work tasks was well
maintained but pulmonary ventilation during work, the O_2 debt and
pulse rate responses to a fixed task indicated some deterioration.
The 1,010 kcal·d^{-1} maintained satisfactory work blood sugar levels
and there was no evidence of poor physiological response to the stress
of work. No important change occurred in grip strength or in the
maximal oxygen intake per kilogram of body weight or fat free tissue
in either experiment. But the total maximal oxygen intake declined
slowly in both experiments. Data from the Minnesota experiment on 6
months of semi-starvation was pooled with the current observations to
show that a marked deterioration in both maximal oxygen intake and
strength as measured by the hand dynamometer took place between a
weight loss of 10 and 16%. It is concluded that when sufficient
calories and NaCl in the presence of an adequate vitamin intake are
provided to prevent ketosis, dehydration and hypoglycemia under
conditions of moderate energy output performance capacity is well
maintained up to a weight loss of 10% of the original body weight.

Konishi, F., J. M. Hawkins, M. I. Grossman, F. M. Berger, G. J. Isaac, and T. E. Friedemann. 1956. The Dietary Composition and Adequacy of the Food Consumed by Soldiers Under an Ad Libitum Regimen. Denver, Colo.: Fitzsimons Army Hospital. Report 184, July, 105 pp.

A food intake study of 98 soldiers under an ad libitum regimen was conducted. The mean intakes per day were: kcal, 3,669; protein, 150.7; fats, 162.3; carbohydrates, 396.6 g. The average gain in body weight was 2.03 kg. An exponential equation was calculated to estimate the calorie requirement of men equivalent in age, body weight, and activity to those in this investigation: $y = 438.01 x 0.473$; y = kcal, x = body weight in kg.

Kreider, M. B., T. Dee, and J. A. Vaughn. 1961. Effect of Reduced Rations and Method of Load Carrying on Physical Fitness and Energy Expenditure of Small Groups of Men Operating on the Greenland Icecap. Natick, Mass.: Quartermaster Research and Engineering Center. Technical Report EP-160, July, 50 pp., illus.

Early in the summer of 1960 a group of 19 young soldiers were transported from Fort Lee, Va., to the Greenland icecap, where they were studied during 2 treks of 10 days each over the icecap. A period of training and acclimatization preceded the studies and some measurements were made both before and after each trek. Finally, some measurements were also made at sea level after return to Natick, Mass. The subjects hiked 8 miles each day, and were divided into 2 major groups: one living on a full ration, and the other on a ration reduced by about 40% of the voluntary caloric intake. Both groups were further subdivided according to either of two methods of load carrying: (1) on the back and sled, (2) entirely on the sled. The method was alternated for each man during the second half of the 10-day period; also the alternate ration regimen was used during the second period. The following measurements were made:

(1) _Physical fitness_ was measured by performance on the Harvard step test before and after each experimental period. After return to sea level, performance on this test was also compared with performance on the treadmill. In addition, the subjects ranked each other by their subjective estimate of fitness.

(2) A mild step test called the Altitude step test was used to compare metabolic and respiratory requirements at the altitude of the icecap (7,000 feet) with that of sea level (actually 165 feet).

(3) _Energy metabolism_ was measured for extended periods during the daily trek by a meter located in a face mask; this used the principle that the energy metabolism is directly related to the respiratory volume. However, after return to Natick, it was necessary to measure this relationship for each man because of individual variation.

(4) _Body weights_ were measured frequently.

It was found that a reduction of caloric intake of about 40% below the voluntary intake and a resultant 4.5% decrease of body weight during 10 days of hard work did not noticeably affect the performance on the Harvard step test in spite of the high level of exercise and also low motivation. There was, however, subjective evidence of deterioration in the form of a greater sense of fatigue, a lack of enthusiasm, and an increased irritability. Other tests for fitness, the treadmill test and subjective evaluation, did not correlate closely with the Harvard step test. Even though the energy cost of work on the icecap decreased from the beginning to the end of the 10-day experimental period, the reduction was not greater on the reduced ration than on the full ration on a body-weight basis. A load was pulled more easily on sled than carried partly on the sled and partly on the back on the type of snow surface present in this study. At around 7,000 feet there was an increase of 8% of the respiratory volume above that at sea level after adjustment to standard temperature and pressure. The volume of inspired air during performance of the mild step test remained higher for at least 12 days after return to sea level. There is some evidence of an inverse relationship between the volume of inspired air and the scores on the Harvard step test.

Levine, L., W. J. Evans, F. R. Winsmann, and K. B. Pandolf. 1982. Prolonged self-paced hard physical exercise comparing trained and untrained men. Ergonomics 25:393-400.

Six fit male subjects (25 years, 180 cm, 72 kg, maximal VO_2 59.0 m, $l \cdot kg^{-1} min^{-1}$) and six sedentary male subjects (24 years, 175 cm, 73 kg, maximal VO_2 = 45.1 $ml \cdot kg^{-1} min^{-1}$) performed self-paced hard physical exercise while walking over a 17.07 km course consisting of four different terrains (blacktop road, 4.02 km; dirt road, 4.65 km; light brush, 4.35 km; and heavy brush, 4.05 km). All subjects walked the entire course as fast as possible carrying no external load, 10 kg, and 20 kg. Time on each terrain for individual subjects was used to determine walking velocity and predicted energy expenditure. Heart rate (HR) was recorded as each subject completed each terrain. Walking velocity and absolute predicted energy expenditure were not different between the two groups ($p > 0.05$), and did not decline with time as the subjects traversed the course for any of the load carriage conditions. Relative energy expenditure, however, was significantly different ($p < 0.01$) between the trained and the untrained subjects (grand means = 35% VO_2max and 44% VO_2max, respectively). Mean HR for the untrained group was also significantly greater ($p < 0.05$) than that for the trained group over each of the four terrains. These data indicate that when men are required to do self-paced hard physical exercise of an extended duration (approximately 2.5-3.5 hours), their walking velocity and energy expenditure will remain constant. Fit individuals may be limited by an inability to walk fast enough to maintain the same

relative energy expenditure as unfit individuals. Consequently fit individuals might be expected to further extend the amount of physical exercise performed without a fall in energy expenditure.

McCarroll, J. E., R. F. Goldman, and J. C. Denniston. Food intake and energy expenditure in cold weather military training. 1979. Mil. Med. 144:606-610.

The energy demands were examined of military activities in a cold environment and the associated food requirements. The metabolic effects of cold on skin temperature are shivering and non-shivering thermogenesis. These effects are negligible for the well-clothed person since the temperature is not lowered. Acclimatization to cold is a complicated phenomenon which has only slight gains in comfort compared with the time required to achieve it. Energy expenditure (activity) is the primary determinant of food requirements. An energy expenditure prediction equation is presented for practical use when the following factors are known: load carried, velocity of movement, and the type of terrain. Estimates of energy expenditure for various military activities are presented, in order to make rough estimates of energy demands upon troops in varying terrains and using different means of mobility. Using these estimates, a scenario can be created and food requirements can be predicted.

Approximate Energy Costs for Activities in Typical Winter Military Training

Activity	Approx. Metabolic Rate (kcal·min^{-1})	Time (hrs)	Energy Cost (kcal)
Heavy activity	7.1	4	1,704
Moderate activity (e.g., walking)	4.8	4	1,152
Light activity	2.6	4	624
Resting (e.g., eating, sitting)	1.5	4	360
Sleeping	1.1	8	528
TOTAL			4,368 kcal·d^{-1}

Molnar, G. W., J. R. Blair, C. W. Gottschalk, W. M. Layton, L. E. Osgood, W. J. Zimmerman, and C. A. Johnson. 1950. Energy Expenditure and Endurance of Men in an Arctic Bivouac. Fort Knox, Ky.: Medical Department Field Research Laboratory. Report 39, Apr., 59 pp.

Seven men were studied in a 14 day temperate bivouac exercise during November and in a 13 day arctic bivouac exercise during the succeeding February.

No significant differences were seen between the arctic and temperate exercises concerning:
   a. energy expenditure (average of 4,000 kcal·d^{-1} per 70 kg man)
   b. basal metabolism
   c. sweat secretion
   d. total urinary nitrogen, non-proteinuria, morning blood sugar, hematocrit, hemoglobin concentration, output of urinary steroids.

Ketonuria, an unidentified reducing substance in the urine, and an unidentified urinary pigment were noted in the arctic exercise situation.

Overall efficiency and performance were reduced in some of the men in the arctic environment.

O'Hara, W. J., and C. L. Allen. 1974. Changes in Body Composition During an Arctic Winter Exercise. Downsview, Ontario: Defence and Civil Institute of Environmental Medicine, Department of National Defence. DCIEM Report 74-R1061, 30 pp.

The effects of long range Arctic winter patrols on body and urine composition were examined in 55 infantrymen during a two-week New Viking exercise. Each man carried 30 kg of clothing and equipment, and for one third of the patrol time would assist in pulling a 180 kg cargo toboggan. During the first week of the Exercise at Fort Churchill, Man. (58°N), the men traversed 25 km in 12 hours at a speed of 2,000 m·h^{-1}. Daily temperatures ranged from -38°F to ± 7°F with a mean of -20°F. Mean wind speed and maximum daily windchill were 16.5 mph and 2,032 kcal·m^{-2}·h^{-1} respectively. During the second week at Frobisher Bay, NWT (63° 45'M), they covered 44 km in 16 hours at a speed of 2,750 m·h^{-1}. Weather conditions were similar to those at Churchill. The men were provided with approximately 3,600 kcal·d^{-1} in rations. Energy expenditure studies indicated an approximate caloric balance. The mean decrease in body weight was 1.0 kg. Skinfold thickness decreased by 38%, equivalent to a 21.9% loss of body fat (4.2). Urinalysis showed an unusually high incidence of proteinuria and ketonuria. (U)

O'Hara, W. J., and C. L. Allen. 1976a. Energy Expenditure Studies Using ECG Telemetry During a Simulated Arctic Military Exercise: "Kool Stool I." Downsview, Ontario: Defence and Civil Institute of Environmental Medicine. DCIEM Technical Report 76-X-44, 32 pp.

A one week simulated Arctic military exercise was undertaken to observe whether certain physiological changes observed during actual two week military patrols in the Canadian subarctic and Arctic would also occur within a cold climatic facility. ECG telemetry was used to monitor heart rates during the simulated patrol activities within the

chamber in order to measure the energy expenditure of the ten Arctic trained infantrymen. The energy expenditure predicted from heart rate during work in the cold facility was 6.0 kcal·min^{-1}, while the mean energy cost of northern winter patrols measured by direct respirometry was 6.3 kcal·min^{-1}. In conjunction with diaries, the mean daily energy expenditure using heart rate techniques was estimated at 3,355 kcal·man^{-1}·d^{-1}, while the value for the respirometry method was 3,358 kcal·man^{-1}·d^{-1}. In the two week northern study, 52 men were observed to have a decrease in mean skinfold thickness of 38%, equivalent to a 4.2 kg loss of body fat, while the ten men in the cold facility sustained a 19% loss in one week, equivalent to a 2.35 kg loss of body fat.

O'Hara, W. J., and C. L. Allen. 1976b. Changes in Body Composition during a Simulated Arctic Military Exercise: "Kool Stool I." Downsview, Ontario: Defence and Civil Institute of Environmental Medicine. DCIEM Technical Report 76-X-54, July, 34 pp.

A one week simulated Arctic military exercise was undertaken to observe whether certain physiological changes observed during actual two week military patrols in the Canadian subarctic and Arctic would also occur within a cold climatic facility. Energy balance studies were conducted; predictions of daily energy expenditure were quite similar for both studies, respective values for the actual and simulated studies being 3,358 and 3,355 kcal·man^{-1}·d^{-1}. While the men in the northern study were estimated to be in caloric balance, the infantrymen in the cold chamber had a daily caloric deficit of over 500 kcal, a total experimental imbalance calculated to be equivalent to a 0.5 kg loss of body fat. In the Arctic, 52 men incurred a 38% reduction in mean skinfold thickness, a loss equivalent to a 4.2 kg depletion of mean body fat over two weeks, while in caloric balance. In the one week simulated study, ten Arctic trained infantrymen had a comparable one week skinfold loss of 19%, estimated to be equivalent to a 2.4 kg loss of body fat . . . a value 4.5 times greater than predicted from energy balance studies. There were physiological indications that dehydration had developed by the conclusion of the study. There was an 80% daily incidence of ketonuria and unexpectedly 50% of the subjects had glucosuria on one or more occasions.

O'Hara, W. J., C. Allen, and R. J. Shephard. 1977. Loss of body weight and fat during exercise in a cold chamber. European J. Appl. Physiol. 37:205-218.

Ten men spent one week in a cold climatic facility performing a simulated arctic military exercise demanding an energy expenditure of 13-16 MJ·d^{-1} (3,100-3,800 kcal·d^{-1}). Although the ration pack was adequate, extensive plate wastage led to a negative energy balance of 2.2 MJ·d^{-1} (525 kcal·d^{-1}). Fluid intake was also

insufficient, with a 3.25% decrease of body weight, and a 9.7% decrease in skin thickness over the cold exposure. Extensive fat mobilization was indicated by a decrease of skinfold thicknesses, an increase of body density, and associated ketonuria and glycosuria. The fat breakdown far exceeded the calculated energy deficit, and it is postulated that much of the "surplus" energy was required for synthesis of additional muscle protein. In the arctic environment, both energy and fluid balances are better maintained because there are few distractions from the simple pleasure of preparing and eating meals.

O'Hara, W. J., C. Allen, R. J. Shephard, and G. Allen. 1979. Fat loss in the cold—a controlled study. J. Appl. Physiol: Respirat. Environ. Exer. Physiol. 46:872-877.

A simple crossover design tested the specificity of fat loss induced by exercise in the cold. Fifteen middle-aged, moderately obese males exercised 2.5 $h \cdot d^{-1}$ for 2 weeks, separated by an intervening (recovery) week. For 1 week, the climatic chamber was maintained at -40°C (still air, full arctic clothing), with ambient temperatures for the alternate week. A total daily energy expenditure of about 13 MJ (3,100 kcal) was estimated from diary records of activity, the tables of Durnin and Passmore, and Kofranyi-Michaelis measurements of oxygen consumption for subjects in the chamber. Comparison with diary records of food consumption showed a small energy deficit ($\sim$2.9 $MJ \cdot d^{-1}$; 690 kcal) over both warm and cold exposures. Cold exposure led to a reduction of skinfold thicknesses and an increase of body density (underwater weighing), with a loss of body fat (2.3 kg from skinfolds, 0.8 kg from underwater weighing) and a 1.5-kg increase of lean body mass. However, no significant changes of body composition occurred with comparable exercise under temperate conditions. Core temperatures were well maintained in the cold environment, but skin temperatures were 10°C lower than under ambient conditions. Mean skin temperature in the cold was positively correlated with fat loss. The observed fat loss in the cold can be explained by 1) new protein synthesis, 2) ketosis, and 3) a small energy deficit.

Pandolf, K. B., B. Givoni, and R. F. Goldman. 1977. Predicting energy expenditure with loads while standing or walking very slowly. J. Appl. Physiol.: Respirat. Environ. Exer. Physiol. 43:577-581.

Previously we presented a formula to predict metabolic rate (M) for walking and load carrying; it could not be used for walking speeds below 0.7 $m \cdot s^{-1}$ (2.5 $km \cdot h^{-1}$). In this study, six men each carried backpack loads of 32, 40 and 50 kg while walking at 1.0, 0.8, 0.6, 0.4, and 0.2 $m \cdot s^{-1}$, to extend the range of speed down to the standstill level. Metabolic cost of standing with 0-, 10-, 30-, or

50-kg backpacks was also investigated in 10 men to evaluate the energy expenditure of load carriage while standing. Energy expenditure increased with external load, both standing and walking. No increased inefficiency occurred with very slow walking; M decreased smoothly as speed approached zero. The revised predictive formula which now covers standing and the whole range of walking speeds, has the form

$$M = 1.5W + 2.0(W + L) (L/W)^2 + \eta (W + L)[1.5V^2 + 0.35VG]$$

where M = metabolic rate, watts; W = subject weight, kg; L = load carried, kg; V = speed of walking, $m \cdot s^{-1}$; G = grade, %; η = terrain factor (η = 1.0 for treadmill). The new formula not only extends the range of application but also allows an adjustment for load as a function of body weight and permits easier calculation of energy expenditure.

Pandolf, K. B., M. F. Haisman, and R. F. Goldman. 1976. Metabolic energy expenditure and terrain coefficients for walking on snow. Ergonomics 19:683-690.

Ten male subjects each walked at two speeds, 0.67 and 1.12 $m \cdot s^{-1}$ (1.5 and 2.5 mph) on a level treadmill, and on a variety of snow depths. Energy expenditure increased linearly with increasing depth of footprint depression and was expressed, considering clothed weight, by the regression equation: energy expenditure ($W \cdot kg^{-1} \cdot h^{-1} km^{-1}h^{-1}$) = 1.18 - 0.089 depression (cm). At 45 cm footprint depression as compared to a 0 cm depression, energy expenditure increased by a ratio of approximately 5:1. Although subjects were considered above average in terms of fitness, average VO_2max = 51.4 $ml \cdot kg^{-1} \cdot kg^{-1} \cdot min^{-1}$ (n = 6), all terminated walking due to exhaustion at an average footprint depth of 35.0 cm at a walking speed of 1.12 $m \cdot s^{-1}$. Practical limits for prolonged snow walking not exceeding approximately 50% VO_2max were developed with 20 cm being the maximal depth at 0.678 $m \cdot s^{-1}$, and 10 cm at 1.12 $m \cdot s^{-1}$ without snow shoes. At increased footprint depths, limiting factors for snow walking were the increasing lift work, inefficient stooping posture and balancing difficulty.

Pimental, N. A., and K. B. Pandolf. 1970. Energy expenditure while standing or walking slowly uphill or downhill with loads. Ergonomics 22:963-973.

Eight fit male subjects (24 yr, 176 cm, 79 kg) stood, or walked at speeds of 0.5 or 0.9 $m \cdot s^{-1}$ for 20 min periods of grades of -10 to +25° with loads of 20 or 40 kg. Energy expenditure (watts) was not significantly different in any of the standing conditions: grade and load increased energy expenditure while standing but not significantly. Although all the standing energy expenditure means were relatively low, high perceived exertion ratings suggest limits to

tolerance time in some of these conditions. All the standing means were significantly lower than the walking means. Walking 0.9 $m \cdot s^{-1}$ on a -10° grade was significantly lower than walking 0.5 $m \cdot s^{-1}$ on a $+10^{\circ}$ grade, which was significantly lower than walking 0.9 $m \cdot s^{-1}$ on a $+10^{\circ}$ grade. In the walking conditions there was a significant difference between loads: means for the 20 kg loads were lower than means for the 40 kg loads. As the condition became more strenuous by increasing load, speed, or grade (while walking), energy expenditure became more sensitive to changes in these variables. The current energy expenditure prediction formula (Pandolf et al., 1977) was found to predict slightly high for the standing conditions, low for walking 0.5 $m \cdot s^{-1}$ on a $+10^{\circ}$ grade, and accurately for walking $0.9 m \cdot s^{-1}$ on a $+10^{\circ}$ grade. In the standing conditions the deviation between predicted and measured was higher at the 40 kg load than at the 20 kg load. The formula in its present form is not equipped to predict for negative grades. The results of this study suggest that the prediction formula may place too much emphasis on the effects of speed and load while standing and walking slowly.

Pimental, N. A., Y. Shapiro, and K. B. Pandolf. 1982. Comparison of uphill and downhill walking and concentric and eccentric cycling. Ergonomics 25:373-380.

Seven male subjects (20 years, 176 cm, 70 kg, 16% body fat) walk on a treadmill at various grades (-15 to +30%) and speeds (up to 1.5 $m \cdot s^{-1}$) carrying loads up to 30 kg. They also performed concentric and eccentric cycling at exercise intensities (EI) ranging from 0 to 260 W (~ 160 kpm$\cdot$min^{-1}). Exercise bouts lasted 20 min. At the same oxygen consumption, eccentric cycling elicited the highest heart rate, followed by downhill walking, uphill walking and concentric cycling. Only the regression line for eccentric cycling had a significantly higher slope than the other three regression lines ($p < 0.05$). Average gross exercise efficiencies for uphill walking and concentric cycling were similar (13.5 and 14.5%), and were significantly different from those from downhill walking (-33.5%) and eccentric cycling (-60.6%). For each type of exercise, absolute efficiency was greater with increasing EI. Actual energy expenditures for walking uphill and on the level were then compared to predicted values using the formula of Pandolf et al. (1977). The formula was found to be accurate for all uphill conditions at 1.12 $m \cdot s^{-1}$. For walking uphill at 0.56 $m \cdot s^{-1}$, the formula predicted slightly low (5-16%) while the formula understimated energy expenditure for level walking by 14-33%. These findings would imply further modifications to this formula are necessary, particularly to include the observations for downhill walking.

Pitts, G. C., F. C. Consolazio, and R. E. Johnson. 1944. Dietary protein and physical fitness in temperate and hot environments. J. Nutr. 27:497-508.

1. The effect of variation in the level of dietary protein upon the physical fitness and metabolism of three subjects was studied under both temperate and tropical conditions while reclining, standing and marching.

2. The urinary nitrogen excretion in grams per day averaged 18.5 during the high protein period, 9.5 during the low protein period and 12.9 and 13.5 during the normal periods before and after the experiment, respectively. There were minor changes in body weight with a maximum during the high protein period. The plasma protein level showed no significant changes.

3. Physical fitness under temperate conditions showed no changes attributable to dietary protein level.

4. Performance of work in both hot, dry and hot, moist environments showed no changes attributable to dietary protein level. In both cases, however, improvements due to training and acclimatization were observed.

5. Metabolism while reclining and while standing was not significantly different in the high and low protein period. Metabolism while marching was slightly lower in the low protein period. However, as judged by actual performance in the heat this was a physiologically insignificant change.

6. It is concluded that even though protein does have a high specific dynamic action, the theoretical objections heretofore raised against a high protein diet in hot environments are unjustified under the conditions of our observations. Protein intake may vary widely from 75 to 150 g daily without effect upon performance of intermittent work in the heat.

Quinn, M., C. R. Kleeman, D. E. Bass, and A. Henschel. 1953. Further Study of Survival Rations with Adequate Water Intake. Lawrence, Mass.: Quartermaster Climatic Research Laboratory. Report 205, Mar., 17 pp.

Ten young, white, normal men lived in a constant temperature chamber at 75°F, 25% relative humidity for a period of 18 days, and were maintained on a nutritionally adequate diet during the first nine days. The subjects were evenly divided into two groups (during the last nine days) and each man received approximately 900 kcal and 1,750 ml of water daily. The calories were derived from 46.25 g of protein, 70.36 g of carbohydrate, and 51.09 g of fat in the Protein Group; and 0.63 g of protein, 116.0 g of carbohydrate, and 51.60 g of fat in the Non-Protein Group. There were similar losses of weight, fat, and water in the two groups, but dehydration was not a prominent feature of the experiment. There was no significant difference in nitrogen balance. The data suggested that the Protein Group lost less potassium but more sodium and chloride. Ketonuria was observed only in the Protein Group. The results indicated no appreciable difference in metabolic performance between the Protein and Non-Protein Groups receiving 900 kcal and 1,750 ml of water daily, and between the

respective groups receiving 800 ml of water daily. The ingested
protein was utilized primarily as a source of fuel.

Quinn, M., C. R. Kleeman, D. E. Bass, and A. Henschel. 1954.
    Nitrogen, water, and electrolyte metabolism on protein and
    protein-free low-calorie diets in man. I. Water restriction.
    Metab. Clin. Exp. 3:49-67.

A metabolic comparison of protein and protein-free diets was made
on 10 young, white, normal males equally divided into two groups.
Each group received 900 kcal and 800 ml of water daily for a period of
9 days.

    1. There were no appreciable differences in electrolyte or
nitrogen balances between the two groups.

    2. Both groups showed negative water balances throughout the
experimental period. The water loss of the protein group exceeded
that of the nonprotein group. The cause of the larger water loss in
the protein group was the increased renal water requirement resulting
from increased excretion of protein metabolites.

    3. The water lost from the body was largely at the expense of the
extracellular water, but dehydration was not a prominent feature in
either group.

    4. Calculated internal balances suggested large losses of cell
potassium and entry of sodium into the cells.

    5. Ketonuria was observed in the protein group, but not in the
nonprotein group.

Added protein at the 900 kcal level increased the loss of body
water, did not appreciably improve nitrogen balance, and was used
largely as a source of energy.

Rochelle, R. H., and S. M. Horvath. 1969. Metabolic responses to food
    and cold stress. J. Appl. Physiol. 27:710-714.

Seven seminude subjects were exposed for 2 hours to ambient
environments of either 25 or 7.5°C. During this time various body
temperatures, VO_2, and caloric heat production were measured. Test
meals providing 213.6 kcal were given in the form of glucose, glycine,
or steak. The specific dynamic effect was determined at 25°C and
the influence of this increased heat production on thermal balance,
shivering, and oxygen uptake in a cold environment was evaluated. It
was concluded that the elevated heat production due to food ingestion
was not effective in altering the tolerance to a standard cold
exposure. An unexplained reduction of shivering was noted in those
subjects who had eaten the glycine test meal before entering the cold
environment.

Rodahl, K. 1954. Nutritional requirements in cold climates. J.
    Nutr. 53:575-588.

A series of nutritional surveys was carried out among two groups of Whites (airmen and Infantry soldiers) in Alaska during the 4 seasons of the year from 1950 to 1952. Simultaneously, similar studies were made among 4 groups of Eskimos for comparison. Individual food weighings showed an average daily kcal consumption per man of 3,000 in the Air Force group and 3,200 in the Infantry group. The average expenditure for the 4 seasons was estimated to be about 2,800 $kcal \cdot man^{-1} \cdot d^{-1}$ on the basis of time activity data. Under these conditions no appreciable weight change occurred, and the subjects remained in excellent health throughout the period of the study. It is concluded that the calorie requirements of the average man engaged in activities of similar magnitude and under similar climatic conditions as those of the subjects studied, would be on the order of approximately 3,000 to 3,500 $kcal \cdot man^{-1} \cdot d^{-1}$ at any season of the year. In adult male Eskimos at 4 different locations in Alaska, an average daily consumption of approximately 3,100 kcal was sufficient to maintain the body weight with an estimated daily energy expenditure of roughly 2,700 kcal throughout the year.

Rodahl, K., and S. M. Horvath. 1962. Effects of dietary protein on physical work capacity during severe cold stress. J. Appl. Physiol. 17:763-767.

The effect of four different diets (I: 3,000 kcal, 70 g protein; II: 3,000 kcal, 4 g protein; III: 1,500 kcal, 70 g protein; IV: 1,500 kcal, 4 g protein) on physical work capacity (treadmill running at 7.5 mph and 8.6% grade) was studied in normal young men at ambient temperatures of 22 and 8° C. In 9 days at 22° C there was no difference between the diets with respect to performance capacity. At 8°C no significant deterioration in physical work capacity was observed in nude subjects living on diet I for 9 days, but a marked deterioration occurred after 5 days on diet IV. A significant deterioration also occurred on diet II, as well as on diet III. It is thus evident that a marked reduction in calories or in protein causes deterioration in physical work capacity in men exposed to severe cold stress. In the cold, resting metabolism of men on all diets increased about twofold, resting pulse rate increased by about 20-30 $b \cdot min^{-1}$ on an average, and the pulse rate at submaximal work load was similarly increased. There was a significant increase in the urinary excretion of catecholamines in the cold.

Sawka, M. N., K. B. Pandolf, B. A. Avellini, and Y. Shapiro. 1983. Does heat acclimation lower the rate of metabolism elicited by muscular exercise? Aviat. Space Environ. Med. 54:27-31.

Heat acclimation has been suggested to either lower or have no effect on the rate of metabolism (M) elicited by muscular exercise. The purpose of the present investigation (Study I) was to examine the effect heat acclimation has on the M ($W \cdot kg^{-1}$ or VO_2 in

ml·kg^{-1}) elicited by muscular exercise. Two additional
investigations were evaluated to determine if season (summer or
winter) of year (Study II) and subject gender (Study III) further
influence the effect heat acclimation has on M during exercise.
Volunteers for Study I (n=15 men), II (n=8 men), and III (n=10 men and
9 women) completed standardized treadmill walks in hot (40°C, 30% rh
or 49°C, 20% rh) and cold (20°C, 40% rh) environments immediately
before and after heat acclimation. After heat acclimation, a lower M
was observed for Study I (-4%; $p < 0.05$), II (9-2%; N.S.) and III
(-3%; $p = 0.06$) in the hot environments. In addition, after heat
acclimation a lower M was observed for Study I (-3%; $p = 0.08$), II
(-5%; $p < 0.05$) and III (-6%; $p < 0.05$) in the cool environment.
Season of year and subject gender did not have a significant effect on
these results. These data indicate that heat acclimation does lower
the M elicited by exercise. The observed percent decrease was lower
in the hot (-3%) than cool (-5%) test environments.

Soule, R. G., and R. F. Goldman. 1969. Energy cost of loads carried
on the head, hands, or feet. J. Appl. Physiol. 27:687-690.

Ten subjects (22 yr, 174 cm, 70 kg) walked for 20 min on a
treadmill at 4.0, 4.8, or 5.6 km·h^{-1} carrying: 1) no load, 2) 4
kg, or 3) 7 kg on each hand, 4) 6 kg on each foot, or 5) 14 kg on the
head. Loads 3, 4, and 5 represented a maximum for these subjects.
Energy cost, expressed as milliliters of O_2 per minute per kilogram
of total weight (man + clothing + load) agreed, for the no load
condition, with our previous studies. The cost per kilogram of weight
carried on the head was 1.2 times the expected cost per kilogram of
the no load condition at all speeds. At 5.6 km/hr, the cost per
kilogram of load carried on the hands was 1.9 times the no load cost
for both the 4- and 7-kg loads; at the slower speeds the cost for the
7-kg load was also 1.9 times the no load cost. However, the 4-kg load
cost per kilogram was only 1.4 times, presumably reflecting
compensations at the lower load and speeds. The cost per kilogram of
load carried on the feet was 4.2 times the no load cost per kilogram
at 4.0 km·h^{-1}, 5.8 times at 4.8 km·h^{-1}, and 6.3 times at 5.6
km·h^{-1}. Since, in this study, the order of presentation was
varied to eliminate training effects, it is impossible to estimate the
extent to which these extra costs might be reduced by training;
however, considering the mechanical leverages, some extra costs must
always be incurred.

Soule, R. G. and R. F. Goldman. 1972. Terrain coefficients for
energy cost prediction. J. Appl. Physiol. 32:706-708.

The energy cost of walking at two speeds for eight men, carrying
three different loads, was measured for six different level terrains.
The measured energy cost for each terrain was compared to predicted
treadmill costs for the same loads and speeds. The loads (including

clothing, gasometer and pack) totaled 8, 20, or 30 kg and were carried at speeds of 0.66 and 1.1 m·s^{-1} for heavy brush, swampy bog, and loose sand and at speeds of 1.1 and 1.55 m·s^{-1} for blacktop road, dirt road, and light brush terrains. The ratios of the measured energy costs to the corresponding treadmill costs provided the "terrain coefficients" for these six terrains. Analysis of data supports the use of a single prediction equation with these derived terrain coefficients for prediction of the energy cost (oxygen consumption) of walking on any of these level terrains with a moderate pack load (10-40 kg) with reasonable precision.

Soule, R. G., K. B. Pandolf, and R. F. Goldman. 1978. Energy expenditure of heavy load carriage. Ergonomics 21:373-381.

Fourteen subjects (22 yr, 175 cm, 72 kg) walked for 20 min on a treadmill at 3.2, 4.8, or 6.4 km·h^{-1} carrying 35, 40, 45, or 50 kg; during a second phase, ten additional subjects (22 yr, 178 cm, 75 kg) attempted to walk for 45 min at the same speeds carrying 60, 65 or 70 kg. Energy expenditure when expressed as ml oxygen per minute per kilogram of total weight (man + clothing + load) agreed for the no load condition with literature values. After deducting the individual's no load cost, the resulting net energy expenditure for carrying the loads, when expressed as ml·kg^{-1}·min^{-1} was generally constant at each speed; i.e., loads from 35 to 70 kg showed no statistical differences in energy expenditure per kilogram at 3.2 and 4.8 km·h^{-1}. At 6.4 km·h^{-1} carrying 70 kg, the average measured cost per kg was statistically different (p < 0.05) than carrying 35 kg at this speed; subjects were working at greater than 90% of their maximal VO$_2$ levels carrying 70 kg. However, similar comparison of the measured cost per kg between loads of 40 and 65 kg was statistically the same at 6.4 km·h^{-1}. The general constancy of measured energy expenditure per kg for loads even up to 70 kg, probably depends on the condition that the load is well balanced and close to the centre of the body. As reported earlier, higher costs are associated with loads in unbalanced positions. Thus, the limitations commonly encountered in load carrying capacity may arise from poor positioning of the load rather than the weight of the load per se.

Stadler, J., and M. I. Grossman. 1955. Food intake of soldiers residing in the subarctic. Denver, Colo.: Medical Nutrition Laboratory, U. S. Army Fitzsimons Army Hospital. Report 161, 10 pp.

The food intake of 7 men was measured for 8 weeks while they resided in shelters at 50°F or 70°F and were outdoors (mean temperature -10°F) marching or performing equivalent activity for 30 to 35 hours per week. The mean intake was 3,733 kcal·d^{-1} with approximately 39% of kcal derived from fat. Body weight remained constant. The mean intake of these same men during a one-week period

in a temperate climate preceding the study in the cold climate was
3,573 kcal·d⁻¹. The subjects consumed 363 ± 48.6 (standard
deviation) kcal per day more while residing in the 50°F shelter than
while residing in the 70°F shelter. This difference is
statistically highly significant. Food consumption decreased after
the first two weeks of the study, but it was not possible to determine
whether this was due to acclimatization of the subjects or to a change
in outdoor temperature.

Strydom, N. B., G. A. G. Bredell, A. J. S. Benade, J. F. Morrison,
   J. H. Viljoen, and C. H. van Graan. 1966. The metabolic cost of
   marching at 3 M. P. J. over firm and sandy surfaces. Int. Z.
   angew. Physiol. einschl. Arbeitsphysiol. 23:166-171.

The study was designed to determine the energy cost of walking over
sandy and firm surfaces, and to compare the physiological responses of
recruits recorded while walking over these surfaces.
The average oxygen intake of 11 young men walking over loose sand
at 3 mph and carrying loads of about 50 lbs each (inclusive of
clothes) was 1.973 L·min⁻¹ as compared with 1.101 L·min⁻¹ for
walking on a firm surface, an increase of 80 per cent. The average
pulse rate and rectal temperature were significantly higher during the
march over sand (150 b·min⁻¹ and 101.5°F respectively) than
while walking over firm surfaces (127 b·min⁻¹ and 100.5°F). The
increased physiological strain was obvious. Most of the men were
working at more than 50 per cent of their estimated maximum oxygen
intakes while walking on sand, as a result of which their heart rates
and rectal temperatures would have increased progressively with time.

Strydom, N. B., C. H. Wyndham, C. G. Williams, J. F. Morrison,
   G. A. G. Bredell, M. J. von Rahden, and J. Peter. 1966. Energy
   requirement of acclimatized subjects in humid heat. Fed. Proc.
   25:1366-1371.

It is generally believed that metabolism increases with an increase
in environmental temperature. This concept is adequately supported by
the work of Christensen (1) and Fuhrman and Fuhrman (7). The latter
demonstrated that the oxygen intake of excised tissue as well as of
experimental animals increases in direct relation to the increase in
temperature. These animals and the human subjects used by Christensen
were, however, not acclimatized to heat and thus were under severe
physiological strain. The increased metabolisms observed in men and
the experimental animals could thus be explained by the extra demands
placed on the cardiovascular system. This effect is, however, reduced
by a process of heat acclimatization and, as was previously shown by
Williams et al. (11), the oxygen intake of highly trained and
acclimatized subjects working at rates above 5,000 ft·lb·min⁻¹
on a bicycle ergometer can be significantly lower in a hot than in a

cool environment. Below 5,000 ft·lb·min^{-1} climate had no influence and metabolism remained constant.

Consolazio and his co-workers, however, recently reported in a number of papers (2-5) that caloric requirements for men working and living in the extreme heat are increased. Their latest study was "designed to rule out the effects, if any, of acclimatization to heat and the effects of training on the metabolic rate." On the basis of their results they suggest that the recommendations of the National Research Council's Food and Nutrition Board and the United Nations Food and Agriculture Organization with respect to energy requirements in heat be re-evaluated. As a first step in this direction it was deemed necessary for an independent research laboratory to either confirm, disprove, or modify Consolazio et al.'s contentions. This study was therefore designed to determine the energy cost of acclimatized subjects when at rest or at work in a range of environmental conditions which varied from mild to severe heat.

Although the oxygen consumptions in heat of our five acclimatized subjects were significantly lower than those of a comparable weight group in cool conditions (12), no valid conclusion can be drawn with respect to differences between them. Our group was very fit and well trained and training has been shown to result in a decreased metabolic rate for a set task (10). The possibility of a lower metabolic rate in heat as observed by Johnson and Kark (8) and recently confirmed by Edholm et al. (6) is, however, not excluded.

Swain, H. L., F. M. Toth, F. C. Consolazio, W. H. Fitzpatrick, D. I. Allen, and C. J. Koehn. 1949. Food consumption of soldiers in a subarctic climate (Fort Churchill, Manitoba, Canada 1947-1948). J. Nutr. 338:63-72.

A study was made of the voluntary food consumption of garrison troops at Fort Churchill, Manitoba, Canada, during 10-day periods in November 1947, February 1948, and April 1948. Each of the three nutrition surveys was conducted on troops who ate together in the same mess and received an abundant ration of fresh and frozen foods, providing 5,500 kcal·man^{-1}·d^{-1} (Canadian Army Arctic Ration Scale 7). The average daily consumption per man, including canteen (post exchange) purchases, in the three surveys was 5,620, 5,590 and 5,690 kcal, respectively. The intake of all nutrients was well above the allowances for active men recommended by the U. S. National Research Council. Throughout the winter the troops were in good health and maintained their body weights. The caloric intake in the three surveys was inversely correlated with the mean outdoor temperatures prevailing at the time of survey, and was directly correlated with the mean windchill. In all three surveys the precentages of calories furnished by protein, fat and carbohydrate remained almost constant, averaging 13, 41 and 46, respectively. These values are not significantly different from those reported many times for United States troops eating a garrison ration in temperate

climates. As judged by the consumption of individual food items, the pattern of food habits was not different in the subarctic climate at Fort Churchill from that in U.S. Army training camps in temperate climates. The surveys were conducted in a mess in which an average of 100 men ate all their meals. The military duties of these men included routine administration and general camp maintenance. Because of the great variety of duties of each man during the winter, it was impractical to secure a uniform record of activity. However, judging by interrogation and observation, the average man was moderately active and spent about three hours daily in the open. There was no evidence of an increased appetite for fats in the subarctic winter.

Taylor, H. L., and L. B. Rowell. 1974. Exercise and metabolism. Pp. 84-111 in Science and Medicine of Exercise and Sports, 2nd ed., W. R. Johnson and E. R. Buskirk, eds. New York: Harper & Row.

A discussion of the relationships between VO_2, rate and type of work, and factors which influence the metabolic pathway used. Work was classified according to energy requirement (unduly heavy = 2.5 L $O_2 \cdot min^{-1}$; light = 0.5 L $O_2 \cdot min^{-1}$). Factors affecting the intake of oxygen include:

1. body weight
2. speed of locomotion
3. grade of the terrain
4. mechanical efficiency.

Teitlebaum, A., and R. F. Goodman. 1972. Increased energy cost with multiple clothing layers. J. Appl. Physiol. 32:743-744.

The question of any increase in energy cost for walking with multiple clothing layers, apart from that increase as a result of added weight per se, was investigated with a seven-layer experimental clothing system. Eight subjects, wearing a standard T-shirt and shorts and fatigue uniform and combat boots (T-shirt and fatigue shirt = 2 layers) walked in randomized sequence on treadmills at 5.6 or 8.0 $km \cdot hr^{-1}$ either wearing an additional five layers of clothing over the fatigues or carrying the 11.19 kg weight of these five layers as a lead-filled belt. Three 2-min respiratory samples were taken during each 20-min trial, at the 6-8, 12-14, and 18-20th min. A mean value of 514 $\pm$ 12.4 (se) W at 5.6 $km \cdot hr^{-1}$ was obtained for the multiple-layer clothing system in contrast to 435 $\pm$ 12.9 W for the equivalent added weight carried at the same speed. At 8.0 $km \cdot hr^{-1}$ the cost for multiple-layer clothing system was 995 $\pm$ 32.3 W compared with 873 $\pm$ 24.9 W for the equivalent weight carried on the belt. These differences were very highly significantly different ($P < 0.001$), with each individual expending more energy walking with the multiple-layer system than with the equivalent weight carried as a belt.

Van Reen, R., D. Minard, A. R. Dasler, N. Raica, Jr., and
R. A. Nelson. 1964. Nutrition of recruits during a summer
habitability study. J. Am. Dietetic Assoc. 45:117-123.

100 Navy personnel participated in a test situation in a hot, humid shelter. Caloric intake averaged 1,641-1,712 $kcal \cdot d^{-1}$ with a substantial percentage from a survival cracker. Mean weight loss was 2.27 kg (5.0 lbs) at a relatively constant rate. Water intake averaged 2.2 $L \cdot d^{-1}$. Water balance was maintained, therefore weight loss was attributed to loss of body tissue rather than dehydration. No statistical change in physical work capacity was noted over the 12 weeks.

Welch, B. E., and P. F. Iampietro. 1956. Caloric intake and energy
expenditure of 11 men in a desert environment. Denver, Colo.:
Fitzsimons Army Hospital. Report 190, Aug., 22 pp.

A series of experiments was initiated to quantitate caloric intake and expenditure in several environments with a well-defined regiment of physical activity. The test site for this study was the hot-dry environment found at the Yuma Test Station, Yuma, AZ.

Caloric intake and expenditure was studied in 11 men during a sojourn in the hot-dry environment found at Yuma, AZ. The mean ambient temperature was 33°C (91°F) and the mean relative humidity was 35%.

1. Caloric intake averaged 2,857 $kcal \cdot man^{-1} \cdot d^{-1}$ during the study. When kcal intake was corrected for the kcal equivalent of body weight loss (0.102 $kg \cdot man^{-1} \cdot d^{-1}$), the average intake was increased to either 3,311 $kcal \cdot d^{-1}$ or 2,878 $kcal \cdot d^{-1}$, depending on whether the correction for change in body fat was based on skinfold thickness or on body water.

2. The dietary composition of the food (percent of kcal) was 12.5% protein, 35.5% fat and 52.0% carbohydrate.

3. Energy expended during the 24-hour period (marching and other activities) averaged 2,977 $kcal \cdot man^{-1} \cdot d^{-1}$.

Welch, B. E., et al. 1955. Caloric intake and energy expenditure in a
sub-arctic environment. Denver, Colo.: Fitzsimons Army Hospital.
Report 173, Dec., 34 pp., illus.

A series of experiments was initiated that were designed to quantify caloric intake and expenditure in several environments, with physical activity well defined. The test site for this study was the sub-Arctic environment with low ambient temperatures and high wind chill, found at Fort Churchill, Manitoba, Canada.

Caloric intake and caloric expenditure were studied in eight men during 10 days of pre-bivouac, 12 days of bivouac and 8 days of post-bivouac. Fort Churchill, Manitoba, Canada was the test site. Mean ambient temperatures for the three periods were -25°C (-13°F), -31°C (-23°F), and -26°C (-15°F), respectively.

1. Caloric intake averaged approximately 3,600 kcal·man^{-1}·d^{-1} for the entire study. The men consumed 3,613, 3,644 and 3,472 kcal respectively during the pre-bivouac, bivouac and post-bivouac periods. Since a weight loss of 1.9 kg occurred during the bivouac period, an estimated correction of caloric requirement for this weight loss would increase it to 4,260 kcal·man^{-1}·d^{-1}. Dietary composition did not change during the three periods of the experiment. The percentage of the total energy of the average food consumed during all periods was 13.8% from protein, 38.5% from fat, and 47.7% from carbohydrate.

2. Energy expended during outdoor activities involving progress across the snow cover at 2.27 mph^{-1} was found to average approximately 7 kcal·min^{-1}·d^{-1} for outdoor activity. Variations were noted in energy expenditure between skiing, snowshoeing and walking over the same snow cover. Snowshoeing was the most economical in this group of men.

3. A comparison was made between studies of caloric intake in Northern latitude areas. It appears that food consumption calculated by the inventory method, using standard food tables, has led to exceptionally high estimates of caloric consumption. Furthermore, it is impossible to interpret the findings of most previous studies because the daily activity level was never clearly established.

Welch, B. E., J. G. Marcinek, E. R. Buskirk, and P. F. Iampietro. 1957. Caloric intake and energy expenditure of eight men in a temperate environment. Denver, Colo.: U. S. Army Medical Nutrition Laboratory. Report No. 196, Jan., 11 pp., illus.

Caloric intake and expenditure were studied in eight men during a 12-day period in a temperate environment at Natick, MA. Outdoor activity consisted of marching 10 to 11 miles per day. The mean ambient temmperature during daylight hours was 22.2°C (72°F), the mean relative humidity was 68%, and the mean windspeed was 2.8 mph.

1. Caloric intake averaged 2,812 kcal·man^{-1}·d^{-1} during the entire study. The range in the average caloric intake was from 2,259 to 3,454 kcal·d^{-1}.

2. Average body weight changed little during the course of the study.

3. Daily energy expenditure (marching and other activities) during the entire study was 2,899 kcal·man^{-1}·d^{-1}, and ranged from 2,625 to 3,163 kcal·d^{-1}.

Widdowson, E. M., O. G. Edholm, and R. A. McCance. 1954. The food intake and energy expenditure of cadets in training. Brit. J. Nutr. 8:147-155.

The energy expenditure of 77 cadets in a training establishment has been estimated and found to average 3,420 kcal·d^{-1}. This is equivalent to published figures for the energy expenditure of men

engaged in moderate work. The cadets spent 9.25 h a day sitting, some of it at lectures, and 8.5 h in bed. Dressing and cleaning uniform occupied more of their time and energy than sport or military training. The supplies issued to the establishment provided 3,714 kcal·man^{-1}·d^{-1}. Of these the cadets took only 68%. Unused bread accounted for a large part of the discrepancy, for the cadets ate only 6.4 oz (182 g) out of the 15 oz (426 g) of their ration. The plate waste came to 7.7% of the calories in the food served. The cadets then bought at the canteen and in restaurants outside food that provided them with approximately the same number of calories as the portion of their ration not taken up. By refusing their allowance of bread and buying cakes instead, they obtained more fat but less protein than their ration supplied.

Winsmann, F. R., and R. F. Goldman. 1976. Methods for evaluation of load-carriage systems. Percept. Mot. Skills 43:1211-1218.

In an effort to evaluate the effectiveness of a new load-carriage system on man, energy cost studies were done comparing the new system with a standard load-carriage system. Three different methods of treadmill walking were used for the comparison: (1) investigator controlled treadmill speed, (2) subject controlled treadmill speed, and (3) heart-rate controlled treadmill speed. Although none is entirely new, these three approaches provide practical means to measure the cost of work. Since there were no statistically significant differences between the two load-carriage systems, it was concluded that as long as weight is properly distributed over the body, weight per se is the most important factor in load carriage rather than the specific load-carriage system design.

These studies clearly support the concept that weight is the most important factor in load carriage and that as long as it is centrally carried on the body rather than out on the extremities, the specific design of the load-carriage system will have little or no influence on either the energy cost of carrying the weight, the voluntary rate of march adopted, or the physiological cost as integrated by the body and displayed by heart rate.

Wyant, K. W., W. C. Wilkinson, H. L. Meiselman, L. E. Symington, and J. G. Hunn. 1980. Performance, Physiological, and Acceptance Tests of a 1,500-kcal Emergency/Assault Food Packet Diet in a Cold Weather Environment. Natick, Mass.: Natick R&D Command. Technical Report NATICK/TR-81/022, Nov., 42 pp.

A cold weather study was conducted at the U.S. Marine Corps Mountain Warfare Training Center in order to assess consumer acceptance of the modified Emergency/Assault Food Packet (E/AP) and to assess performance and physiological effects of the ration at two different caloric levels. During a five-day exercise in a cold-weather climate, one group of Marines was issued the standard C

rations (3,550 kcal) while half of a second group were issued one E/AP per day (1,500 kcal) and the other half, two E/AP's per day (3,000 kcal). Acceptance was measured using rating scales during face-to-face interviews and performance was measured by three-mile runs and snowshoe runs. Heart rates were continuously monitored, and repeated measurements were made on a symptoms questionnaire.

Results indicated that the E/AP is a highly acceptable ration that holds up well, with some minor exceptions, under field conditions. Generally, performance or physiological differences were detected either between E/AP and C ration groups or within the E/AP group between the 1,500 and 3,000 kcal groups. The short duration of the test and mild environmental conditions mitigated against obtaining differences. Further, the heart rate data is based on a small sample. However, greater quantities of water were purportedly required by the E/AP group, not only for rehydrating food but also for drinking.

BIBLIOGRAPHY ON WATER UTILIZATION

Beisel, W. R., R. F. Goldman, and R. J. T. Joy. 1968. Metabolic balance studies during induced hyperthermia in man. J. Appl. Physiol. 24:1-10.

Metabolic responses in men were studied during hyperthermia induced by humid heat. Conditions in an environmental chamber were adjusted to increase rectal temperatures $0.1-0.2°C \cdot h^{-1}$ for 18 h and to hold them at 39.4°C for 6 h. After rising initially, skin temperature followed a similar pattern. Urinary 17-OHCS, 17-KS, and pregnanetriol increased during hyperthermia and afternoon plasma 17-OHCS concentrations failed to fall. Negative nitrogen, potassium, and magnesium balances were produced by diminished dietary intake, increased urinary excretion, and sweat losses. Urinary sodium and chloride fell abruptly; their renal retention persisted 3 days following heat exposure. Orally administered tap water during a continuing production of sweat caused dilutional decreases in concentration of serum inorganic elements. Hypophosphatemia was exaggerated, possibly because of respiratory alkalosis. Phosphate losses in urine and sweat were minimal, preventing appreciable loss of body phosphorus. Adrenal responses and alterations in nitrogen metabolism during artificial hyperthermia resembled changes seen in infectious fevers. In contrast, body salt and water metabolism was influenced by greater sweat losses during induced hyperthermia.

Brebbia, D. R., R. F. Goldman, and E. R. Buskirk. 1957. Water vapor loss from the respiratory tract during outdoor exercise in the cold. J. Appl. Physiol. 11:219-222.

The water vapor contained in oral expired air was collected during rest and exercise in a subarctic environment in 26 experiments on three men. Heat loss via this route was about 9% of the total energy expenditure. Water vapor loss was directly proportional to ventilation volume. An average (β coefficient) of 32 mg of water was collected from each liter of expired air.

Buskirk, E. R., and W. P. Beetham. 1960. Dehydration and body temperature as a result of marathon running. Med. Sportiva 14:493-506.

Measurements of body weight loss, rectal temperature, and skin temperature were obtained on well-conditioned runners before and after marathon races in cool weather. Results from three races are reported: Boston Marathon, Brighton Road Race, and a practice race. The average body weight losses as a result of each race were respectively 6.0, 4.8, and 4.1% of the starting body weight. Rectal temperatures remained within limits commonly observed for severe activity. The respective averages for the three races were: $38.9^{\circ}C$ ($102.1^{\circ}F$), $35.5^{\circ}C$ ($101.4^{\circ}F$), and $38.1^{\circ}C$ ($100.6^{\circ}F$). Mean weighted skin temperature (estimated from three skin sites) was lower after than before each rate. As a result of the decrease in skin temperature and the elevation in rectal temperature, mean body temperature did not change. The relationship between percent body weight loss and rectal temperature after racing was found to be $r = +0.58$. This value was significantly different from 0 at the 0.01 level. A dehydration of 1% (body weight loss) was associated with approximately a $0.30^{\circ}C$ ($0.54^{\circ}F$) elevation in rectal temperature.

Buskirk, E. R., P. F. Iampietro, and D. E. Bass. 1958. Work performance after dehydration: effects of physical conditioning and heat acclimatization. J. Appl. Physiol. 12:189-194.

Three groups of five men each were dehydrated overnight in the heat ($115^{\circ}F$) on two occasions (D_1 and D_2) to approximately 5.5% of their starting body weight. During the 3-week period between D_1 and D_2, one group (AC) was acclimatized to heat and physically conditioned, the second group (C) was physically conditioned and the third group (S) remained sedentary. The response to work after dehydration was assessed by the following criteria: pulse rate (P), rectal temperature (T_r) and maximal oxygen intake (Max. VO_2). Pulse rates during and after walking and after running were elevated with dehydration. This elevation was reduced in groups AC and C at D_2 as compared to D_1, but not in group S. An elevation in T_r with walking also occurred with dehydration, but this elevation was not significantly different at D_2 as compared with D_1 in any group. Physical conditioning elicited an elevation in Max. VO_2 (group AC and C), but the elevation was no greater in group AC than in group C. Dehydration was associated with an equal decrement in Max.

VO_2 at D_1 and D_2 in all groups, but conditioned men (AC and C) maintained a relatively higher Max. VO_2 than group S. Thus, physical conditioning was associated with enhanced work performance during dehydration (assessed by the above criteria), whereas acclimatization to heat did not appreciably supplement this effect.

Buskirk, E., P. F. Iampietro, B. E. Welch, and J. G. Marcinek. 1957. Caloric Intake and Energy Expenditure of Eight Men in a Temperate Environment. Natick, Mass.: Quartermaster Research and Development Center. Technical Report EP-52, Mar., 13 pp., illus.

Caloric intake and expenditure were studied in eight men during a twelve day period in a temperate environment at Natick, Massachusetts. Outdoor activity consisted of marching 10 to 11 miles per day. The mean ambient temperature during daylight hours was 22.2^oC (72^oF), the relative humidity was 68%, and the mean windspeed was 2.8 mph. Caloric intake averaged 2,812 $kcal \cdot man^{-1} \cdot d^{-1}$. Average body weight changed little during the course of the study. Daily energy expenditure (marching and other activities) during the entire study was 2,899 $kcal \cdot man^{-1} \cdot d^{-1}$ and ranged from 2,625 to 3,163 $kcal \cdot d^{-1}$.

Costill, D. L., R. Cote, E. Miller, T. Miller, and S. Wynder. 1975. Water and electrolyte replacement during repeated days of work in the heat. Aviat. Space Environ. Med. 46:795-800.

In an attempt to determine the value of replacing sweat losses with an electrolyte solution, 12 subjects (2 women and 10 men) were dehydrated (-3% body weight) on 5 successive days. During one 5-d sequence, the subjects replaced fluid losses with a glucose-electrolyte solution, while water was the only fluid ingested during a second 5-d series. With the exception of the drink, daily ionic and caloric intakes were identical for the two 5-d conditions. Measurements of water and electrolyte losses in sweat and urine showed a positive balance in body $Na+$, $K+$, and $Cl-$ during both water (W) and electrolyte solution (ES) treatments. Subjects accumulated significantly more $Na+$ during the W experiments (392 $mEq \cdot 5d^{-1}$) than when the electrolyte solution was ingested (334 $mEq \cdot 5d^{-1}$). As a result, the extracellular fluid compartment, represented by plasma volume, increased 12.2 and 9.0% during the 5-d sequence of the W and ES trials, respectively. It was concluded that the addition of electrolytes to drinking water is of minimal value for subjects who dehydrate (-3%) on repeated days and are permitted to ingest food and drink ad libitum.

Costill, D. L., W. F. Kammer, and A. Fisher. 1970. Fluid ingestion during distance running. Arch. Environ. Hlth. 21:520-525.

Four highly trained marathon runners were studied to determine the influence of fluid loss and replacement on selected physiological variables. Each runner performed three two-hour treadmill runs at about 70% of his aerobic capacity to assess the value of drinking a glucose-electrolyte (GE) solution or water ingestion (WI) during exhaustive work. When fluids were ingested during the treadmill runs, a leveling of rectal temperature was observed after about 45 minutes of exercise. Glucose-electrolyte feedings maintained the serum electrolytes near the pre-exercise level, elevated the blood glucose, and maintained carbohydrate metabolism during the final 60 minutes of running. Measurements of the gastric residue after exercise showed no significant difference between the GE and WI volumes. The rate of gastric emptying, fluid loss, and international rules reduce the effectiveness of drinking fluids during marathon competition.

Costill, D. L., and K. E. Sparks. 1973. Rapid fluid replacement following thermal dehydration. J. Appl. Physiol. 34:299-303.

On three separate occasions eight male subjects were studied during thermal dehydration (-4% body weight) and rapid fluid replacement. The purpose of these studies was to assess the effectiveness of rapid fluid ingestion in restoring plasma and its constituents to the prehydration level. In two of the experiments the men replaced their body fluid losses by ingesting either demineralized water (DW) or a glucose-electrolyte solution (GE). During a third dehydration experiment the subjects were studied without rehydrating (NF). During the DW and GE trials, the men replaced their body fluid losses in 13 feedings evenly spaced over a 3-hr period. Plasma volume decreased 12% (following dehydration) and heart rates during exercise were 20 $b \cdot min^{-1}$ above the prehydration level. In the DW and GE studies exercise heart rates were normalized after replacing about 62% of the subjects' body weight deficit. It was concluded that rapid fluid replacement following thermal dehydration does not effectively restore plasma volume or serum osmolality to the predehydration level within 4 h of these observations.

Dill, D. B., M. K. Yousef, and J. D. Nelson. 1973. Responses of men and women to two-hour walks in desert heat. J. Appl. Physiol. 35:231-235.

Performances of men and women walking in desert heat at 100 $m \cdot min^{-1}$ were compared. Seven of eight men walked for 2 h in the afternoon with ambient temperature ranging from 37 to 47°C while three girls generally were unable to complete a 2-h walk in the forenoon with ambient temperatures of 31-42°C. Each subject walked twice without drinking and twice with periodic replenishment of water and salt losses in sweat. In the men the mean change in weight with water and salt replenished was -0.12 kg; those without water to drink lost 2.03 kg. Periodic ingestion of the cold salt solution lessened

the rise in rectal temperature and in heart rate. There was no effect
of replenishment on sweat rate nor on chloride concentration in
sweat. Attempts to estimate plasma volume changes as related to
replenishment were inconclusive. It appears that in a 2-h walk
increase in serum protein concentration is not a reliable indicator of
plasma volume decrease because of loss of protein from the
circulation, nor is the CO method for blood volume reliable because of
uncertainty about the ratio of central to venous hematocrit at the end
of the 2-h walk. It appears that if subjects walking for 2 h in
desert heat are instructed to drink periodically an amount of salt
solution that balances salt and water losses in sweat their body
weight is maintained and their cardiovascular system benefited.

Francis, K. T. 1979. Effect of water and electrolyte replacement
during exercise in the heat on biochemical indices of stress and
performance. Aviat. Space Environ. Med. 50:115-119.

Eight healthy young men exercised on alternate days in a warm,
humid environment ($32^{o}C$, 65% RH) at 50% VO_2max for 2 h while
receiving water supplement (WS), glucose-electrolyte solution (ES), or
no fluid supplement (NS). The average weight loss after 2 h of
exercise and NS was 2.44 kg with a resultant plasma volume decrease of
17%. This acute period of exercise with no fluid replacement elicited
significant increments in serum levels of cortisol,
dopamine-B-hydroxylase and uric acid. Alternatively, exercise in the
heat for the same duration with water or electrolyte supplement failed
to effect significant alterations in any of these physical or
biochemical factors compared to preexercise levels. Heart rates under
the influence of heat stress and exercise with NS averaged 18% higher
at each time period studied compared with WS or ES.

Grande, F., J. T. Anderson, and H. L. Taylor. 1957. Effects of
restricted water intake on urine nitrogen output in man on a low
calorie diet devoid of protein. J. Appl. Physiol. 10:430-435.

Urine nitrogen was measured in three groups of young men receiving,
respectively, daily water allowances of 900 ml, 1,800 ml and
unrestricted quantity. Food was restricted to 1,000 kcal of
carbohydrates, 4.5 g of NaCl and vitamins. The men were required to
expend about 120 kcal daily in walking. The daily urine nitrogen
output at the 5th experimental day (adjusted to 70 kg body weight)
averaged 9.4 g for the men on 900 ml of water, 7.1 g for the men
receiving 1,800 ml of water and 5.8 g for the men on water ad
libitum. Nitrogen in the feces was unchanged and that in the sweat
was either unchanged, or slightly decreased, by water restriction.
The increase in nitrogen excretion paralleled the degree of
dehydration. An elevation of the blood urea nitrogen was observed by
the 5th day of combined food and water restriction in the men on 900
ml of water. On rehydration about 34.4 g of urea nitrogen was washed

out, giving rise to a transient continuation of the high urine nitrogen excretion. The increase nitrogen excretion is considered as a metabolic response to the stress of dehydration, partly related to increased activity of the adrenal cortex glands. This catabolic response does not help the body to economize water, as illustrated by the fact that the men receiving the smallest water allowance excreted more urine water than their mates with a more liberal water allowance at the day of their maximal dehydration.

Grande, F., J. E. Monagle, E. R. Buskirk, and H. L. Taylor. 1959. Body temperature responses to exercise in men on restricted food and water intake. J. Appl. Physiol. 14:194-198.

Rectal temperatures (T_r) of 12 clinically healthy soldiers were measured in a room at 25.5°C and 40-45% relative humidity during a 1 hour walk on a motor driven treadmill at 3.5 mph and 10% grade, during control with adequate food intake and water ad libitum, and during a period of food and water restriction. The daily water intake during the water restriction period was 900 ml for six of the men, Low Water group (LW), and 1,800 ml for the other six, High Water group (HW). The restriction of water began at the same time as the restriction of food and lasted 5 full days for the LW group and 10 full days for the HW group. Food was restricted to 1,000 kcal from carbohydrate, 4.5 g of NaCl and a multi-vitamin pill/day for 16 days. Water ad libitum was given throughout the experiment except for the period of water restriction. The LW group showed a progressive increase of T_r at the end of the walk during the water restriction period with average T_r 1.51°C, higher at peak dehydration than in control. In the HW group the greatest average increase, 0.46°C, was observed on day 5 of restriction. Administration of water ad libitum brought the work T_r back to the control level in the LW group. The relationship between dehydration, elevation of T_r during work and changes in sweat rate is discussed.

Grande, F., H. L. Taylor, J. T. Anderson, E. R. Buskirk, and A. Keys. 1958. Water exchange in men on a restricted water intake and a low calorie carbohydrate diet accompanied by physical work. J. Appl. Physiol. 12:202-210.

After 21 days of control 12 soldiers subsisted for 16 days on 1,000 kcal from carbohydrate, 4.5 g NaCl and one multivitamin tablet per day. Six of the men received 900 ml of water daily during the first 5 days of food restriction, the other six were allowed 1,800 ml per day during the first 10 days. Water ad libitum was given for the rest of the experiment. Physical work equivalent to about 1,200 kcal·d^{-1} was performed regularly throughout. The men ate, worked and slept in an air-conditioned suite at 78°F and 40-45% relative humidity. Average weight loss at the end of 5 days of food and water restriction was 6.41 kg (8.5%) for the men receiving 900 ml H_2O, and 4.37 kg

(6.0%) for those receiving 1,800 ml. Water balance was -5.0 kg and
-3.0 kg, respectively. Another 13 men under similar conditions but
receiving water ad libitum had an average weight loss of 3.1 kg (4.5%)
and a water balance of -1.8 kg. Through decrease of output, water
equilibrium was attained by the men on 1,800 ml water on and after the
6th day of combined food and water restriction. Both water restricted
groups showed marked decreases of sweating during work and of
insensible loss during sleep. When water was given ad libitum sweat
and insensible loss rose and when the normal diet was reinstituted
they rose still further.

Greenleaf, J. E. Dehydration-induced drinking in humans. 1982. Fed.
    Proc. 41:2509-2514.

Mechanisms of drinking have been studied extensively in laboratory
mammals, but comparatively little information is available on human
consumption of fluids. The assumption that osmotic disequilibrium
between extra- and intracellular fluid can be rectified within seconds
may not be true for plasma and red blood cell (RBC) fluid in humans
inasmuch as stress induced hyperosmotemia to +13 $mosmol \cdot kg^{-1}$ does
not cause a significant change in mean RBC corpuscular volume. Unlike
some mammals, humans have a delay in rehydration (involuntary
dehydration) after fluid loss. Two factors unique to humans that
probably contribute to involuntary dehydration are 1) upright posture
and 2) extracellular fluid and electrolyte loss by sweating from
exercise and heat exposure. If drinking is influenced by upright
postural changes, it may be related to increased plasma renin activity
(PRA) but not to increase in plasma osmolality or arginine vasopressin
concentration. Under combined stresses of heat, exercise, and prior
dehydration, exercise is the greatest inhibiting factor and heat
exposure has the least inhibitory effect on voluntary water intake.
The rate of drinking during exercise in heat has a high correlation
with sweat rate but is essentially unrelated to the well-established
dipsogenic factors of plasma volume, osmolality, and PRA. However, it
is likely that some or all of these dipsogenic factors act to initiate
drinking in humans.

Greenleaf, J. E., E. G. Averkin, and F. Sargent II. 1966. Water
    consumption by man in a warm environment: a statistical analysis.
    J. Appl. Physiol. 21:93-98.

Twenty-two metabolic variables were examined using stepwise linear
regression analysis for their possible relationship to voluntary water
consumption in 87 young men. Six variables: 1) mean daily urinary
vol., 2) serum osmolarity, 3) lying pulse rate, 4) mean daily urinary
Cl, 5) mean daily urinary K, and 6) rate of sweating accounted for 62%
of the variation in water intake. The addition of the remaining 16
variables accounted for only 71% of the variation. An equation was
constructed that estimated water intake from these six variables. The

anions, particularly Cl, might be of greater importance in influencing drinking than has been previously realized. The data suggest that some combination of body osmolarity and body fluid volume is associated with voluntary water intake in man.

Greenleaf, J. E., P. J. Brock, L. C. Keil, and J. T. Morse. 1983. Drinking and water balance during exercise and heat acclimation. J. Appl. Physiol.: Respirat. Environ. Exer. Physiol. 54:414-419.

The purpose of this study was to describe the interactions between drinking and plasma volume, ions, osmolality (Osm), vasopressin (PVP), and renin activity (PRA) during exercise and heat-induced dehydration. Voluntary H_2O intake ($16^{\circ}C$) was measured in a group of five men (21-24 yr) undergoing acclimation during ergometer exercise (75 W) in a warm environment for 2 $h \cdot d^{-1}$ ($T_{db}39.8^{\circ}C$, rh 50%) for 8 consecutive days. A control group of five men (19-22 yr) underwent a similar regimen in a thermoneutral environment (T_{db} $23.8^{\circ}C$, T_{wb} $16.9^{\circ}C$, rh 50%). Fluid intake in the control group varied between 129 and 233 $ml \cdot h^{-1}$ during the 2 h of exercise; it increased from 450 $ml \cdot h^{-1}$ on day 1 to about 1,000 $ml \cdot h^{-1}$ on days 5-8 in the acclimation group. The average level of negative H_2O balance was about 400 ml (52% of total replacement) in the control group and decreased from 900 ml on day 1 to 800 ml [60 to 30% ($P < 0.05$) of replacement] on days 5-8 in the acclimation group. Increased drinking during acclimation was characterized by a progressively shortened time to the first drink (from 26 to 11 min, NS) and a threefold increase to 9.5 drinks/exposure ($P < 0.001$). Mean volume per drink increased from 96 ml in control to 174 ml ($P < 0.01$) during acclimation. Changes in plasma sodium ion concentration, Osm, and PVP were minimal during both experiments, whereas exercise hypovolemia and PRA were significantly greater during acclimation. Thus reduction in body fluid volumes and the reninangiotensin II system appear to be more closely associated with the control of drinking during dehydration induced by exercise in heat than is the sodium ion-osmotic-PVP pathway.

Johnson, R. E. 1964. Water and osmotic economy of survival rations. J. Am. Dietetic Assoc. 45:124-129.

Water and osmotic balance are mutually related. An osmotic deficit leads to a water deficit because the kidney's ability to retain water is diminished. An osmotic plethora leads to a water deficit through osmotic diuresis, i.e., an obligatory loss of water to remove excess osmotically active substances.

These considerations must be taken into account in providing water and food for survival. The questions of prime importance are water, total calories, osmotic intake, non-ketogenicity, and non-toxicity. Even the best survival ration can only slow down functional deterioration; it cannot prevent it. A poorly conceived survival

ration is worse than starvation because it can lead to clinical syndromes, such as orthostatic hypotension, dehydration exhaustion, anhidrosis, and renal dysfunction. The same survival ration can be used in all environments.

Under identical conditions of environment, physical work, water supply, and diet, there is large inter-individual variability, but a consistent intra-individual pattern in the water economy. Water sufficient to maintain a positive water balance for one person will not necessarily suffice for another.

The imposition of a progressively increasing water deficit is not necessarily accompanied by a quantitatively appropriate thirst response. Heat, exercise, and a water deficit all affect the drinking pattern. After severe conditions, a water deficit may not be repaid in 8 hr. of recovery.

Only after a severe water deficit of 2.5 liters or more is there a diminution in the rate of sweating under given conditions. This diminution is not large, only about 50 $ml \cdot h^{-1}$ when the total rate is 500 ml or over.

Bouts of exposure to physical work and a water deficit do not lead tc an improved water balance. In other words, one cannot be "trained" to get along with decreasing amounts of water.

Krzywicki, H. J., C. F. Consolazio, H. L. Johnson, W. C. Nielsen, and R. A. Barnhart. 1971. Water metabolism in humans during acute high-altitude exposure (4,300 m). J. Appl. Physiol. 30:806-809.

During 6 days of altitude exposure at 4,300 m, the following changes in body water compartments were observed, a) Total body water was significantly decreased by 2.25 kg during the 6 day altitude exposure, b) Extra-cellular water appeared to increase by 1.27 kg at altitude, although not significantly, c) Intracellular water, in turn, was significantly decreased by 3.52 kg at altitude, which is contrary to some previous reports. Under the conditions of this study, with heavy physical activity prior to and during altitude exposure, and with fairly high food intakes (above 3,400 $kcal \cdot d^{-1}$), it appeared that hypohydration and diuresis still occurred during acute altitude exposure. This suggested that body water loss may have been an adaptive mechanism in acute altitude exposure.

Moroff, S. V., and D. E. Bass. 1965. Effects of overhydration on man's physiological responses to work in the heat. J. Appl. Physiol. 20:267-270.

The question was asked whether men could work in the heat with less physiological strain if they drank water in excess of expected fluid losses than if they merely replaced their losses as they worked. Thirty volunteer soldiers walked on 2 successive days for 90 min at 3.5 mph on a level treadmill, at a temperature of 120/80°F dry bulb/wet bulb. Each man drank 2,000 ml water before the walk on one

day and no water before the walk on the other; 1,200 ml were drunk
during the walk on both days. Overhydration resulted in significantly
higher sweat rates than did the control state. Two matched groups of
six men each were then acclimatized to heat by daily 100-min walks
under the conditions described abo e. One group was overhydrated
during each day of the acclimatizing period; the other was not.
Overhydration did not affect the pattern of acclimatization to heat;
conversely, acclimatization to heat did not alter the above-described
acute response to overhydration. The hypothesis that overhydration is
beneficial to men working in the heat was supported by this study.

Myles, W. S., and S. D. Livingstone. 1974. Physiological Studies on
New Viking Winter Exercises: Dehydration. Downsview, Ontario,
Defence and Civil Institute of Environmental Medicine. DCIEM
Operational Report 74-OR-1002, Feb., 9 pp.

Considerable emphasis was placed on preventing dehydration; it
appears that this objective was achieved. The maximum weight loss
observed was 2.9 kg (3.7%). Smaller weight losses, and even a small
gain in weight, were seen on some portions of the exercises. It is
likely that a portion of any observed weight loss was due to a
decrease in body fat content. Measurement of total body water
indicated that no significant dehydration occurred. The extent of
dehydration, if any, on Exercise New Viking, therefore appears to be
small and probably had little adverse effect on performance.

In the Arctic dehydration may result from cold-induced diuresis,
increased respiratory water loss, and sweating due to over-heating
when working in Arctic clothing. This effect may be compounded by a
decrease in fluid intake due to a lack of potable water which must be
obtained by melting snow.

Dehydration was assessed from measurements of body weight, skinfold
thickness and total body water (TBW). A subjective estimate was also
obtained of the incidence of thirst and fluid intake.

		N	Body Wt. (kg)	TBW (L)
Serial 55	Pre-exercise	10	76.6	48.4
	Post-exercise	10	74.8	46.9
	Significance		$p < 0.01$	n.s.
Serial 56	Pre-exercise	13	78.9	47.1
	Post-exercise	13	79.5	50.8
	Significance		n.s.	$p < 0.01$

Natick R&D Command. Proceedings 3rd International Meeting, Food for the Armed Forces. 1975. Natick, Mass.: Natick R&D Command. Technical Report 76-42 OTD-USA, Oct., 3 pp.

Variability of Water Requirements:

1. One additional liter of water$\cdot$man$^{-1}\cdot$d^{-1} for each additional 5 kg body weight above 69 kg.
2. Can save up to 4 l$\cdot$man$^{-1}\cdot$d^{-1} by working at night, sleeping by day.
3. A 70-kg man can tolerate a 2% dehydration without difficulty but rectal temperature will rise 0.5°C for each additional 1% dehydration. 10% is associated with walking difficulties.
4. Water should be "comfortably cool"--about 23°C--and either unflavored or slightly tart but not sweet.
5. Water supplies should err on the plus side rather than risking deficits.

Refsum, H. E., B. Tveit, H. D. Meen, and S. B. Stromme. 1973. Serum electrolyte, fluid and acid-base balance after prolonged heavy exercise at low environmental temperature. Scand. J. Clin. Lab. Invest. 32:117-122.

To acquire a broad picture of the consequences of heavy muscular exercise of prolonged duration at low environmental temperature, 41 men, mean age 33.2 years (21-54) were studied before and after a 90-km cross-country ski race, at 0°C, with snow-fall and a contrary wind, with mean finishing time 8.09 hours. An estimate, based on the mean intake of fluid and sugar (2.37 and 0.29 kg), weight loss (1.93 kg), and other data on the metabolic cost of skiing, suggested a well-maintained free water balance. Serum creatinine, urea and phosphorus, whole blood lactate and β-hydroxy-butyric acid rose significantly ($p < 0.001$), whereas serum Mg and Ca, plasma HCO_3, and whole blood pH, P_{CO2} and Hb fell significantly ($p < 0.001$), and serum Na, K, Cl, total cation, and protein remained unchanged ($p > 0.05$). With the exception that the pre-exercise serum creatinine and urea were higher in subjects above 35 years (mean 44.9) than in those below (mean 25.7) ($p < 0.001$), and the increase in serum creatinine was clearly higher in the older men ($p < 0.005$), there were no marked differences between the observations in the older and younger participants. It is concluded that strenuous exercise of long duration under the present circumstances led to remarkably small disturbances in fluid, electrolyte and acid-base balance, also in the relatively older subjects.

Rogers, T. A., J. A. Setliff, and J. C. Klopping. 1964. Energy cost, fluid and electrolyte balance in subarctic survival situations. J. Appl. Physiol. 19:1-8.

In two experiments a total of 12 men were subjected to 5 days of
starvation under survival conditions in the winter subarctic. They
wore flying clothing rated at 3.5 clo. The caloric cost as calculated
from oxygen consumption was 2,300 kcal·m^{-2} for the first day and
2,000 kcal·m^{-2} for subsequent days at ambient temperatures of -30
C. At -10 C the cost of subsequent days fell to 1,500 kcal·m^{-2}.
The subjects lost 8% of body weight but regained 5% body weight after
5 days refeeding on a barely maintenance diet. One-third of the
original (8%) weight loss was due to an isotonic contraction of
extracellular fluid. Changes in heart rate, pulse pressure, and
hematocrit consistent with this fluid contraction were observed.
Although the water intake did not exceed the 5-day urine volume (5
liters), the subjects did not experience thirst until after return to
the warm conditions.

St. Rose, J. E. M., C. L. Allen, W. S. Myles, B. H. Sabiston,
    T. E. Brown, P. J. Anderson, and S. D. Livingstone. 1972. A Study
    of Energy Expenditure, Dehydration and Health in Canadian Troops
    During a Spring Exercise in the Subarctic--Exercise Northern
    Ramble. Downsview, Ontario: Defence Research Board, Department of
    National Defence. DCIEM Report 882, Sept., 40 pp.

Total body weight measurements before and after the exercise showed
no significant change in body weight. No evidence of
hemoconcentration was found in the randomly selected participants of
Exercise Northern Ramble who were studied. Results of total body
water determinations employing the deuterium oxide technique confirmed
the absence of dehydration. Absence of obvious symptoms of
dehydration reflects the mild environmental conditions, the lack of
strenuous physical activity and the ready availability of potable
water.
The extent to which dehydration may be a problem during military
exercises undertaken in more severe Arctic conditions remains to be
investigated. The possible effects of a sodium chloride supplement in
combating dehydration must also be assessed. It is recommended that
these studies be carried out during cold-weather exercises of the New
Viking type. The approach should include measurement of changes in
body weight, body water and plasma volume, as well as changes in urine
composition (volume, specific gravity and metabolic products, e.g.,
ketones).

Strydom, N. B., and L. D. Holdsworth. 1968. The effects of different
    levels of water deficit on physiological responses during heat
    stress. Int. Z. angew. Physiol. einschl. Arbeitsphysiol.
    26:95-102.

The influence of different levels of water deficit on the
physiological responses to heat stress of two well-acclimatised
subjects was studied. The subjects worked continuously at a rate of

2,000 ft·lb·min^{-1} for four hours at 32.2°C T_{wb}, 33.9°C T_{db}, and an air velocity of 0.25-0.4 m·s^{-1}. Man, even when in water deficit, operates most efficiently when he replaces all the fluids lost in sweat and urine by drinking water in small amounts at frequent intervals. When a specific level of water deficit is maintained thoughout the 4 hours of heat exposure body temperature, heart rate, and sweat rate reach equilibrium at values which are significantly different from those recorded under conditions of complete water balance; the more severe the level of dehydration the higher the body temperature and heart rates, and the lower the sweat rates. No indication of any failure of the temperature regulating mechanisms or fatigue of the sweat glands was found and a possible explanation for this difference with previously reported results is provided.

Strydom, N. B., C. H. van Graan, and L. D. Holdsworth. 1965. The water requirements of humans. J. Occup. Med. 7:581-587.

The phenomenon of survival is explained by the fact that the body, deprived of food, is able to convert stored fat and body protein to provide the necessary energy. Unfortunately, the body has no mechanism available to provide itself with adequate amounts of water. Any reasoning, using food restriction as analog, that man can operate efficiently for extended periods of time without water is fraught with danger. There is no evidence in the literature that man can adapt to a diminished water supply or that he carries a reserve of water in his body. The maximum possible amount of water that can be synthesized from the oxidation of food, i.e., 37 ml·d^{-1}, barely equals the amount lost daily by insensible sweating.

Strydom, N. B., C. H. van Graan, J. H. Viljoen, and A. J. S. Benade. 1968. Physiological performance of men subjected to different water regimes over a two-day period. S. A. Med. J. 42:92-95.

Thirty men were observed over a period of two days, during which time they were required to walk a total distance of 25 miles over a desert-like area. They carried packs weighing approximately 45 lb. and walked at 3-3.5 mph. At the end of the walk on the second day they had to shoot at targets at various ranges. The environmental data collected showed that the climatic conditions were not severe. The highest globe temperature recorded was 112°F, while dry-bulb temperatures remained below 85°F for most of the time. In spite of this, the group of men who were given two bottles (2.04 litres) of water·man^{-1}·d^{-1} became severely 'dehydrated'. As a result, the body temperatures of 4 of the 10 men rose to dangerously high levels of 103°F or above. Their heart rates were excessively high, while sweat rates were decreased. The physiological stress imposed was so severe that these men barely managed to complete the walk on the second day.

The group provided with one gallon·man^{-1}·d^{-1} (4.543 litres) performed fairly well on the first day, but progressively developed a greater water deficit on the second day. At the completion of the walk on the second day, an average rectal temperature of 101°F was recorded and heart rates were similar to those of the above group. The marksmanship of these two groups was affected, resulting in 15-20% lower scores than on control days.

The men who were given water ad libitum gave by far the best performance. Their body temperatures and heart rates were comparatively low, and not higher than would be expected from subjects doing the same level of exercise in cool environments. Their marksmanship was unaffected by the walk.

The effects of a water deficit on the morale and drive of the men in the two water-restricted groups were obvious. Behavioural and symptomatic effects became more pronounced as the extent of water depletion increased on the second day. Appetites were poor, and during the intermediate afternoon and evening these men were listless and morose.

Strydom, N. B., C. H. Wyndham, C. H. van Graan, L. D. Holdsworth, and J. F. Morrison. 1966. The influence of water restriction on the performance of men during a prolonged march. S. A. Med. J. 40:539-544.

Two groups of 30 men each were made to carry out a route-march of 18 miles in full army kit. The members of one group were supplied with water ad libitum and those of the other group were rationed to 1 litre of water during the march. Temperature conditions during the study were mild. Dry-bulb temperatures did not exceed 31.1°C (88°F), the wet-bulb temperature was about 19°C (66°F) and globe temperature readings varied from 37.8° to 49°C (100°-120°F) depending upon the degree of cloud cover.

Twelve of the 30 men given only 1 litre of water and 8 of the 30 men given water ad lib failed to complete the march. Of those who fell out, 7 of the men on 1 litre of water collapsed while only 1 of the men given water ad lib collapsed. Bootrub accounted for 16% of the total casualties in both groups. The final average rectal temperature of the water-restricted group was 38.8°C (101.8°F), compared with 38.3°C (101°F) for the ad lib water group. Oral temperatures proved to be quite useless as a means of detecting rise in body temperatures; oral temperatures fell and rectal temperatures rose as the march progressed, and at the end of the march there was an average difference of 2.2°C (4°F) between oral and rectal temperatures. The average water losses in sweat were 4.5 litres in both groups of men. Taking into account water requirement for body function for the rest of the 24 hours, an amount of at least 7 litres (12 pints)·man^{-1}·d^{-1} is required for men engaged in similar activities in the summer of temperate regions. The group of men provided with only 1 litre of water exhibited dehydration to an extent

of 5%, at which level they showed low morale and lack of motivation, became quarrelsome and difficult to control and refused to continue the route-march.

Wyant, K. W., and P. L. Caron. 1983. Water discipline and an arctic ration prototype. Mil. Med. 148:435-439.

Observations from two early cold weather consumer acceptance tests of the Food Packet Assault (FPA) suggest that participants were not receiving enough water to either quench their thirst or to rehydrate their meals. The possibility of voluntary dehydration and the water requirements imposed by a high sodium dehydrated diet prompted an assessment of water discipline in a consumer acceptance test of the Arctic Ration prototype (AR).

Urine samples were collected on four different occasions and a symptoms questionnaire describing symptoms of dehydration was administered at three different times to 17 Marine Corps personnel, who were subsisting on the AR and who were participating in the NATO exercise Cold Winter 81. Samples were collected following 2.5 days in the field, following several days in camp and aboard ship ("baseline" measure), and following 5.5 days in the field. Subjects, as well as members of their company, who also received the AR, completed a post-exercise questionnaire. In addition, a company of Marines who received a British arctic ration (British 24-Hour Ration Pack Arctic) completed a similar questionnaire. Maximally concentrated urines were found following each field exercise, and reported water consumption was far below the amount needed to maintain body fluid balance.

Results suggest that participants had voluntarily dehydrated and indicate that water discipline was very poor. Further, participants reported that there was not enough water available, and differences obtained on several self-report items on the symptoms questionnaire correspond well with the objective measures. Strict water discipline must be imposed if voluntary dehydration is to be avoided and if maximal performance is to be maintained.

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UNITS OF MEASUREMENT AND ABBREVIATIONS

Time

s: second(s)
min: minute(s)
h: hour(s)
d: day(s)
wk: week(s)
mo: month(s)
yr: year(s)

Distance

m: meter(s)
mi: mile(s)
km: kilometer(s)

Speed

$m \cdot h^{-1}$: meter(s) per hour
$mi \cdot h^{-1}$ or mph: miles(s) per hour
$km \cdot h^{-1}$: kilometer(s) per hour
$m \cdot d^{-1}$: meter(s) per day
$mi \cdot d^{-1}$: mile(s) per day
$km \cdot d^{-1}$: kilometer(s) per day

Weight or Mass

g: gram(s)
kg: kilogram(s)
lb: pounds(s)

Volume

ml: milliliter(s)
l: liter(s)

Energy

kcal: kilocalorie(s)
$kcal \cdot min^{-1}$: kilocalorie(s) per minute
$kcal \cdot h^{-1}$: kilocalorie(s) per hour
$kcal \cdot d^{-1}$: kilocalorie(s) per day

Oxygen Utilization

VO_2: rate of oxygen use
$ml \cdot kg^{-1} \cdot min^{-1}$: milliliter(s) per kilogram per minute
VO_2max or Max VO_2: aerobic capacity or maximal oxygen intake

ENERGY CONVERSION FACTORS

Heat represents the expression of human energy exchange. Heat is generated from most bodily activities, even when a person is at rest or asleep. The more physically active the person, the more heat that is generated and the more heat that must be dissipated for the body to remain in thermal equilibrium. When physical activity is undertaken, mechanical work is done; 10 to 30 percent of the energy used is applied to the external load, and the remainder is dissipated as heat.

Different units can be used in expressing energy exchange, but most nutritionists and physiologists use "kilocalories" (kcal).

International convention stipulates the joule (J), or its derivative, the watt (W). Some sources use the British thermal unit (Btu).

$$1 \text{ kcal} = 4,184 \text{ J or } 4.184 \text{ kJ (kilojoules)}$$
$$1 \text{ kcal} \cdot \text{min}^{-1} = 69.7 \text{ W or } 238 \text{ Btu} \cdot \text{h}$$
$$1 \text{ kJ} = 0.25 \text{ kcal}$$
$$1 \text{ kcal} \cdot \text{h}^{-1} = 1.16 \text{ W}$$
$$100 \text{ W} = 1.43 \text{ kcal} \cdot \text{min}^{-1} \text{ or } 341 \text{ Btu} \cdot \text{h}^{-1}$$
$$100 \text{ Btu} \cdot \text{h}^{-1} = 0.42 \text{ kcal} \cdot \text{min}^{-1} \text{ or } 1,046 \text{ W.}$$

The rate of human energy turnover varies considerably, from that of a person resting or asleep (about $1.1 \text{ kcal} \cdot \text{min}^{-1}$ or 77 W) to that of a person performing sustained intense exercise ($15 \text{ kcal} \cdot \text{min}^{-1}$ or 1,046 W).

SPECIAL CONSIDERATIONS REGARDING ENERGY TURNOVER

A variety of factors that affect energy turnover are listed in Table E-1. The list is not comprehensive, but includes factors important in military operations. Buskirk and Mendez (1980*) have discussed several of them in some detail.

Age and Energy Utilization

Energy utilization is affected by two groups of age-related phenomena: (1) growth, maturation, and continued physical development in the late teens and early 20s; and (2) reduction in fat-free body weight, reduction in lean body mass, accumulation of body fat, and the associated reduction in the resting metabolic rate beyond the early 20s. Eighteen-year-olds enter military service while still growing and developing, and energy is required to support these processes. In general, men of age 18 to 22 need about $200 \text{ kcal} \cdot \text{man}^{-1} \cdot \text{d}^{-1}$ more than those of age 23 to 30 who have achieved full physical development. Among women, the corresponding difference is only about $100 \text{ kcal} \cdot \text{women}^{-1} \cdot \text{d}^{-1}$. Beyond the peak years (ages 23 to 30) there is a gradual reduction in resting metabolic rate—another $100 \text{ kcal} \cdot \text{man}^{-1} \cdot \text{d}^{-1}$ and $75 \text{ kcal} \cdot \text{women}^{-1} \cdot \text{d}^{-1}$. If through regular exercise fat-free body weight and lean body mass are maintained from age 20 to 65, the age-related reduction in resting metabolism will be minimized. The Recommended Dietary Allowances of the National Academy of Sciences are tabulated by assuming a 2-percent decrease in resting metabolic rate per decade.

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*Full bibliography information for citations in this section can be found in the appropriate bibliography or list of selected reviews and general references within this appendix.

Table E-1 Factors Affecting Energy Turnover or Exchange

Physical	Environmental
Age	Temperature
Sex	Humidity
Body Weight	Radiant Heat
	Sun
Body Composition	Surrounding Surfaces
	Sky
Body Size (Surface area (SA),	
or Effective SA)	Wind
	Velocity
Resting Metabolism	Direction
Fitness	Precipitation
	Rain
Muscular Strength	Hail
	Snow
Movement Efficiency	
	Terrain
Skill	Hard Surface
	Turf
Emotional Stress-Fear	Mud
	Sand
Other	Gravel
	Rocks
Acclimatization Status	Mountains
	Snow
Clothing (Including Footwear)	Ice
	Low Brush or High Grass
Load Carrying	Jungle
Weight	
Configuration	
Body Attachment	
Task Efficiency	
Vehicular Transport	
Work/Rest Cycles	
Sleep	

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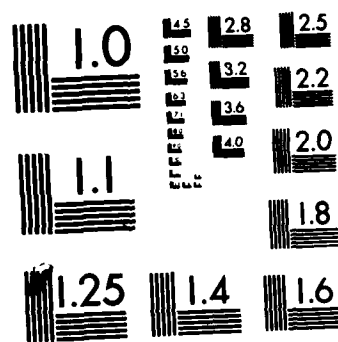   RESEARCH   F R FISHER OCT 83 DAMD17-82-C-2306

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Physical Activity

The primary variable determining energy needs is the amount of physical activity regularly undertaken. For garrisoned troops, regular activity is usually set by the daily routine in the job or training assignment and supplemented by leisure activity. For troops on training maneuvers or in combat, physical activity can range from light to heavy, and the associated increment in energy needs can range from 300 to 1,500 $kcal \cdot man^{-1} \cdot d^{-1}$. According to Recommended Dietary Allowances, the adult energy requirement for moderate activity is about 1.7 and 1.6 times the resting energy expenditures for men and women, respectively.

Table E-2 provides some estimates of daily energy expenditures for different military activities. The list was modified from a tabulation in the 1980 Recommended Dietary Allowances that originally came from the work of Durnin and Passmore (1967).

Body Mass and Load Carrying

Body size and body weight are important determinants of energy turnover. It was pointed out previously that resting energy metabolism depends on lean body mass. In addition, energy expenditure during any physical activity depends on the total weight transported, whether it be body weight or the load carried. Recommended Dietary Allowances states only that "persons of larger (or smaller) body size require proportionately more (or less) total energy per unit of time for activities, such as walking, that involve moving mass over distance." In the equations for walking developed by Goldman and Iampietro (1962), Givoni and Goldman (1971), Soule and Goldman (1972), and Pandolf et al. (1977) that address body weight and load transported, the coefficients of 1.5 to 2.0 indicate the significant effects of these variables on energy expenditure. Considerations of transport and of the time spent in walking and load carrying are quite important in determining daily energy expenditure. Such general treatments of carrying loads, however, apply to loads carried in packs or belts attached to the trunk or waist. Loads carried in the hands or attached to the lower leg or feet require more energy to transport.

Terrain Coefficients

The energy cost of carrying loads when walking can vary considerably with terrain. Soule and Goldman (1972) determined relative values for walking over different surfaces, using treadmill walking (1.0) as the basis for the comparison. They derived the following values:

Table E-2 Examples of Daily Energy Expenditure Increments of a Mature
Man or Woman Engaged in Representative Military Duties

| Activity Category[a] | Man, 70 kg | | | Woman, 58 kg | |
	Time (hr)	Rate (kcal·min^{-1})	Total (kcal)	Rate (kcal min^{-1})	Total (kcal)
Sleeping, reclining	8	1.0-1.2	540	0.9-1.1	440
Very light Seated and standing activities, painting, auto and truck driving, laboratory work, typing, playing musical instruments, equipment cleaning, and maintenance	12	up to 2.5	1300	up to 2.0	900
Light Walking on level, 2.5-3 mph, garage work, electrical work, carpentry, cook, mess hall helper	3	2.5-4.9	600	2.0-3.9	450
Moderate Walking 3.5-4 mph, walking in loose sand or fairly deep snow, load and stacking rations, scrubbing floors, setting up bivouacs	5	5.0-7.4	1500	4.0-5.9	1200
Heavy Walking with loads uphill, forced marches, work with trenching tools, dragging sleds, sustained firing of artilery pieces	2	7.5-12.0	1200	6.0-10.0	960

SOURCE: Adapted from Durin and Passmore, 1967

Treadmill	1.0
Blacktop	1.0
Light brush	1.2
Heavy brush	1.5
Swamp-bog	1.8
Loose sand	2.1.

Pandolf et al. (1976) extended this type of anaysis to walking through snow, obtaining the relative values that appear in Table E-3. General equations for carrying loads while walking at various speeds over various grades and surfaces have been prepared by the same authors.

Climate

Although most military duties are performed under relatively comfortable ambient conditions and military clothing is designed to minimize thermal stress, environmental exposure is often unavoidable. There is evidence that both caloric and water requirements increase with sustained exposure to cold and that water requirements increase with sustained exposure to heat. The extra energy required in the cold is associated with the heavier clothing that must be worn, the "hobbling" effect of the clothing, shivering, and voluntary movements to keep warm. In addition, if ice or snow fields must be traversed, energy expenditure increases if the ice is slippery, if the snow is deep, and if special gear must be worn (such as ice creepers, crampons, snowshoes, or skis). If loads are hauled in sleds, energy expenditure is appreciable and daily needs may exceed 4,000 $kcal \cdot man^{-1} \cdot d^{-1}$.

The increase in energy expenditure under hot conditions is controversial. Heat acclimatization of trained troops tends to minimize the thermally induced increase in metabolism associated with higher core temperature. Thus, increases in energy requirements associated with operations conducted in heat more likely result from transversing difficult terrain (such as loose sand) or from performing duties more rapidly than usual (because of exposure to sunlight, blowing sand, etc.) than from the heat itself.

Table E-3   Relative Values for the Increment in Energy Expenditure
Associated With Walking Through Snow

Speed km·h^{-1}	(mi·h^{-1})	Snow Depth (cm)	Relative Increment
2.4	(1.5)	10	1.9
2.4	(1.5)	20	2.8
2.4	(1.5)	30	3.8
2.4	(1.5)	40	4.7
2.4	(1.5)	50	5.6
4.0	(2.5)	10	2.8
4.0	(2.5)	20	3.1
4.0	(2.5)	30	3.8
4.0	(2.5)	40	4.5
4.0	(2.5)	50	5.2

Values for the relative increment are multiples of the energy
expenditure during level walking on a treadmill.

SOURCE: Adapted from Pandolf et al. (1976).